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Passenger Car Fuel Economy: EPA and Road
A Report to the Congress

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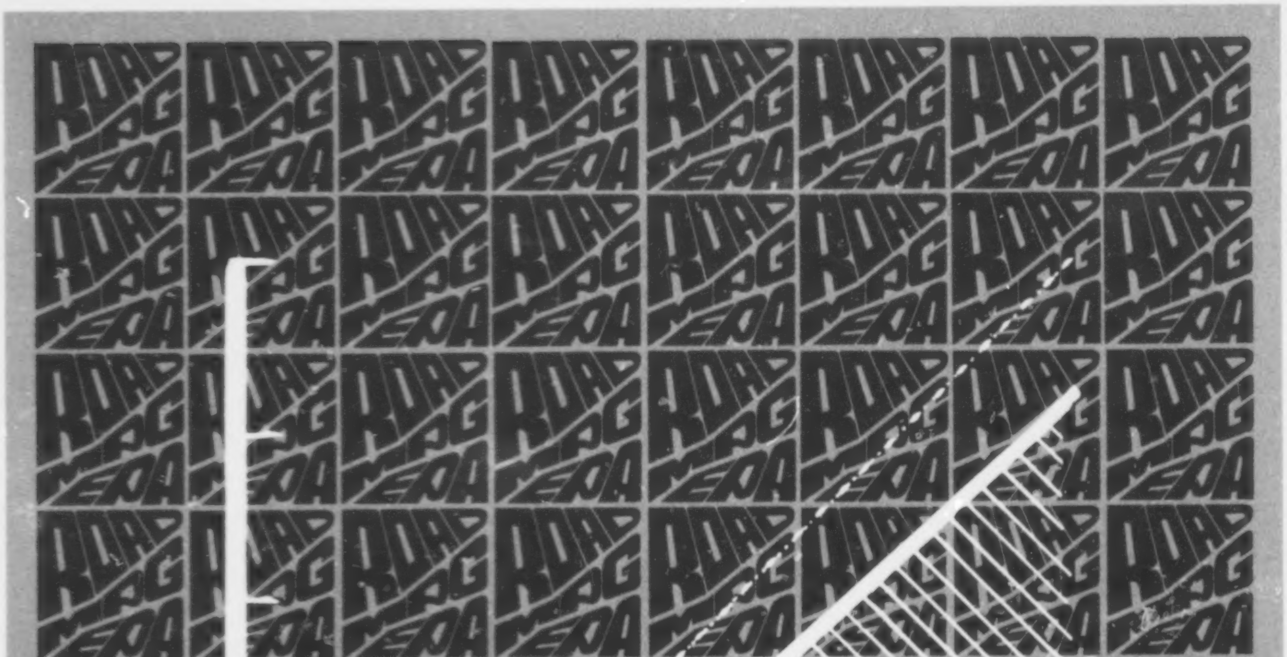

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16. ABSTRACT

In accordance with the National Energy Conservation Policy Act of 1978, Title IV, Part 1, section 404, this report has two objectives.

1.) To determine the degree to which "EPA MPG" figures used in fuel economy labels and gas mileage guides provide realistic estimates of average in-use fuel economy.

2.) To provide a technical basis for revising, as necessary, the label and guide MPG figures to better agree with average in-use fuel economy, and, further, to provide information on the degree to which specific in-use fuel economy influences can cause departures from the standardized label and guide fuel economy figures.

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PASSENGER CAR FUEL ECONOMY: EPA AND ROAD

—A REPORT TO THE CONGRESS—

in response to

THE NATIONAL ENERGY CONSERVATION POLICY ACT OF 1978,
PUBLIC LAW 95-619, TITLE IV, PART 1, SECTION 404

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I. INTRODUCTION AND EXECUTIVE SUMMARY

This report responds to requirements of the National Energy Conservation Policy Act of 1978, Public Law 95-619, at Title IV, Part 1:

Title IV	- Energy Efficiency of Certain Products and Processes
Part 1	- Energy Efficiency Standards for Automobiles

"SEC.404. STUDY.

Within six months after the date of the enactment of this Act, the Environmental Protection Agency, in consultation with the Secretary of Energy and the Secretary of Transportation and after an opportunity for public comment, shall submit to the Congress a detailed report on the degree to which fuel economy estimates required to be used in new car fuel economy labeling and in the annual fuel economy mileage guide required under section 506 of the Motor Vehicle Information and Cost Savings Act (15 U.S.C. 2006) provide a realistic estimate of average fuel economy likely to be achieved by the driving public. Such report shall include such recommendations as the Environmental Protection Agency deems appropriate based on the report and written findings or conclusions stated therein, other than recommendations concerning changes or alterations in the testing and calculation procedures and methods measuring fuel economy under such Act as utilized by the Environmental Protection Agency for model year 1975 passenger automobiles. Nothing in this section shall authorize such agency to make any changes or alterations in such procedures and methods in effect for such model year for measuring automobile fuel economy."

Pertinent to this report also is the Joint Explanatory Statement of the Committee of Conference, Senate Report 95-1294, at the same Title and Part:

> *"Section 404. Study.*
>
> *Section 404 requires the EPA Administrator to conduct a study which compares the mileage estimates for automobiles derived from EPA test procedures with the actual performance by these automobiles. The EPA Administrator must report his findings to the Congress. The report should be sufficiently detailed so that consumers will be able to better evaluate the fuel efficiency of the automobiles they intend to purchase and should include the comments of the Secretary of Energy and Transportation. For example, the report should discuss the deviation from EPA published mileage estimates which are caused by particular driving habits or by the addition of particular optional equipment. The report should therefore not be merely the percentage by which all automobiles in the aggregate deviate in actual performance from EPA mileage estimates.*
>
> *The EPA Administrator is not to focus his study on possible changes of EPA test procedures used for testing automobile fuel efficiency, and the report is not to contain recommendations in this area. The conferees have no intention of authorizing any change in the test procedures as established for model year 1975, and the statutory language specifically prohibits such changes. The test procedures required to be used under EPCA are those for the 1975 model year, and they are not to be amended. The conferees recognize that any change in these test procedures would effectively change the fleet average mileage standards in EPCA. Such a 'change in the rules' for the testing of automobiles, except by statute, is therefore, prohibited."*

OBJECTIVES OF THIS REPORT

In accordance with Section 404 and the Conference Report, this report has two objectives:

1. To determine the degree to which "EPA MPG" figures used in fuel economy labels and gas mileage guides provide realistic estimates of average in-use fuel economy.

2. To provide a technical basis for revising, as necessary, the label and guide MPG figures to better agree with average in-use fuel economy and, further, to provide information on the degree to which specific in-use fuel economy influences can cause departures from the standardized label and guide fuel economy figures.

CONCLUSIONS

Conclusion 1. On the average, fuel economy label and mileage guide figures have been higher than in-use fuel economy since 1976.

Discussion:

The published EPA fuel economy figures vary somewhat from model year to model year. As shown in the table following, the 1974 gas mileage guide* included a single figure based on the 1972 urban emission test procedure. The average EPA fuel economy based on this figure significantly understated in-use fuel economy, an observation which played a strong role in the addition of a non-urban test to the Federal fuel economy information program.

The 1975 labels and guides included two fuel economy figures, a "City" value based on the [slightly-modified] urban emission test, and a "Highway" value based on the new non-urban fuel economy test. There was either an average 1% road MPG overage, or a 29% road shortfall, depending upon which of the two published EPA numbers is used for the comparison.

When the Congress, via the 1975 Energy Policy & Conservation Act, established the "combined City-Highway" MPG figure as the compliance value for the Average Fuel Economy Standards, this figure was added to the 1976 labels and guides, and presented more prominently than the City and Highway figures. For the 1976-78 models, there was a 19-20% road MPG shortfall relative to the combined MPG figure. In light of this, the label and guide protocols were revised to return to the City figure alone, beginning with the 1979 model year.

Comparisons: Fleet Average Road MPG
versus Fleet Average EPA MPG

Model Year	Road MPG	EPA City MPG	Road Comparison	EPA Combined City-Hwy MPG	Road Comparison	EPA Hwy MPG	Road Comparison
1974	13.2	11.5 (1972 test)	+15%				
		12.0 (1975 test)	+10%	14.2	-7%	18.2	-27%
1975	13.8	13.7	+1%	15.8	-12%	19.5	-29%
1976	14.1	15.2	-7%	17.5	-19%	21.3	-34%
1977	14.7	16.0	-8%	18.3	-20%	22.3	-34%
1978	15.8	17.0	-7%	19.6	-19%	24.1	-34%
1979	16.9	17.6	-4%	20.1	-16%	24.3	-31%

Denotes the MPG Values Used in the Labels and Guides.

---

*There were no fuel economy labels in 1974.

The foregoing data and discussion lead to three sub-conclusions:

1A. In-use fleet fuel economy has varied from 10% above the EPA "1975 Test" City MPG, to 8% below it, over the six model years beginning with 1974. For 1979, the most recent year studied, average in-use MPG is 4% lower than this EPA figure.

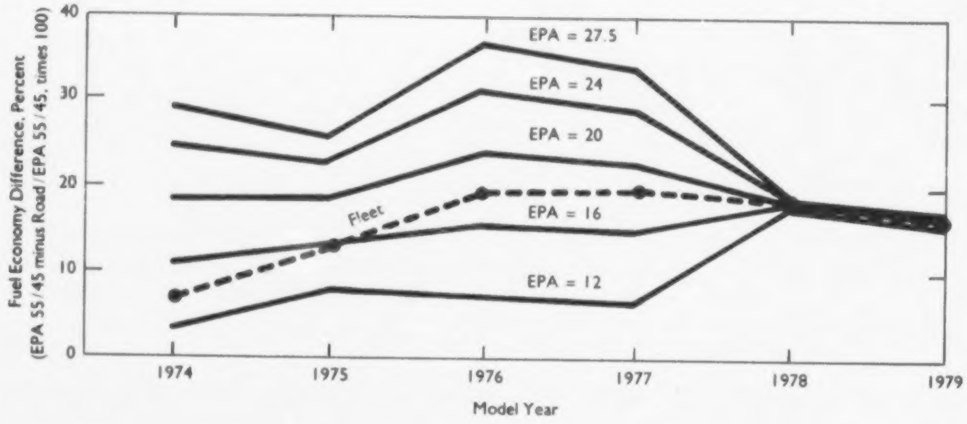
1B. The Combined City-Highway fuel economy figure has always overstated average in-use MPG. The same is true of the Highway figure, but the overstatement has been significantly larger. The Highway figure was never intended to, and certainly does not, represent average in-use fuel economy.

1C. By any measure (City, Highway, or Combined MPG) the fleet average EPA fuel economy figures grew increasingly optimistic with respect to road experience through 1977, after which EPA-to-road shortfalls have been decreasing.

Note: The 1979 in-use data is predominantly that of one manufacturer, Ford Motor Co.

Conclusion 2. For higher-MPG cars, i.e., those most likely to dominate the fleet in the future, road shortfalls have improved recently from 1974-75 levels, following an initial worsening in 1976 and 1977. For lower-MPG cars, i.e., those disappearing year by year from the fleet, road shortfalls worsened through 1978, and have stabilized or perhaps improved slightly in model year 1979. This is illustrated in the following figure.

FIGURE ES-1. Model Year Trends in Fuel Economy Shortfalls (Percent MPG Difference)



Conclusion 3. As of model year 1979, the Congress' EPCA fuel economy standards implied a cumulative improvement in road MPG of 33% over that of 1974. The actual improvement in road MPG has been 28%, as illustrated in the next table.

Fleet Fuel Economy Changes, Road MPG

Model Year	Target Road MPG[a]	Cumulative Change from 1974	Actual Road MPG	Cumulative Change from 1974
1975	14.1	6.7%	13.8	4.5%
1976	15.0	13.3%	14.1	6.7%
1977	15.9	20.0%	14.7	11.3%
1978	16.8	26.7%	15.8	19.5%
1979	17.6	33.3%	16.9	27.5%
1980	18.5	40.0%	----- No Data ------	

---

[a] Based on road fuel economy of 13.2 MPG for 1974, and a straight-line increase of 0.88 MPG per year toward a cumulative 40% improvement by 1980.

3A. The 33% implied improvement in EPA MPG by 1979 has been exceeded.

Fleet Fuel Economy Changes, EPA MPG

Model Year	Target EPA MPG[a]	Cumulative Change from 1974	Actual EPA MPG	Cumulative Change from 1974[b]
1975	14.8	6.7%	15.8	11.1%
1976	15.7	13.3%	17.5	22.9%
1977	16.7	20.0%	18.3	28.9%
1978	17.6(Std=18.0)	26.7%	19.6	37.7%
1979	18.5(Std=19.0)	33.3%	20.1	41.5%
1980	19.5(Std=20.0)	40.0%	22.4	57.4%

---

[a] EPA 55/45 basis; Based on an EPA fuel economy of 13.9 MPG for 1974 (The best estimate at the time of announcement of fuel economy improvement goals), and a straight-line increase of 0.93 MPG per year toward a cumulative 40% improvement by 1980.

[b] Based on the current EPA 55/45 MPG estimate for 1974, 14.2 MPG.

3B. In model years 1975 through 1977, 67%, 54%, and 60% of intended annual road fuel savings occurred; in the model years 1978 and 1979, 77% and 87% of intended yearly fuel savings were realized (calculated assuming a constant fleet size for all model years).

3C. Achievement of the road fuel economy targets would have corresponded to a reduction in U.S. passenger car fuel consumption by approximately 7.4 billion gallons during 1979, compared to 1974; however, due to the shortfall, the actual reduction in road fuel consumption was less, approximately 5.4 billion gallons during 1979.

In terms of barrels per day (B/D) the target savings are 485,000 B/D and the actual savings were 351,000 B/D.

Conclusion 4. Three broad categories of factors are responsible for the difference between EPA MPG and average in-use MPG:

- The travel environment: weather and road conditions;
- Representativeness of EPA test vehicles and test procedures;
- Owner travel and driving habits and vehicle maintenance.

Discussion:

For the model years studied, each of these three categories of factors has roughly the same relative contribution to the total shortfall. Analysis of the shortfall-producing potential of the many individual MPG influences shows that their aggregate effect is more than enough to explain the observed in-use shortfalls.

Any effort directed toward minimizing or eliminating in-use MPG shortfalls must recognize, as inescapable fact, that no one sector--government or industry or the public--has control over all of the factors which determine in-use fuel economy. The weather and the driving public can easily combine to produce better or worse in-use MPG than would be indicated by the "best, most realistic" test, whatever that is.

RECOMMENDATIONS

Recommendation 1. The DOE should continue the acquisition and analysis of data on in-use fuel economy, making such data available to EPA as a matter of routine. Additional data are needed on light trucks and vans, imported vehicles, and consumer-driven vehicles.

Recommendation 2. All government sectors which can influence advertising should encourage consistency between advertising usage of MPG figures and those values used for the label and gas mileage guide system. Currently, use in advertising of the Highway MPG value, which does not appear in the label or in the guide, may be resulting in consumer overoptimism and confusion.

Recommendation 3. The DOE and the EPA should continue to pursue their campaign to expand public awareness of the Federal fuel economy information program (as mandated by EPCA, the Energy Policy and Conservation Act, PL 94-163), incorporating both public input and motivation/media techniques into the program in order to promote the widespread availability of not only improved average MPG numbers, but also, information with which consumers can:

- adjust MPG figures to better predict their own personal fuel economy, and
- purchase, maintain, and operate vehicles so as to reduce fuel consumption.

CONTENT OF THE BALANCE OF THE REPORT

Section II - Background

Presents a discussion of the role and evolution of fuel economy figures, and considers the use of the EPA fuel economy values as relative and absolute measures.

Section III - In-Use Data

Discusses the in-use data used for this report, describes analysis techniques used, treats the representativeness of the data bases, and considers the trend in MPG shortfall with successive model years.

Section IV - Fuel Economy Influences

Introduces and compartmentalizes the factors which influence vehicle fuel economy, and analyzes these factors, arriving at estimates of their relative contribution to differences between EPA and in-use fuel economy.

Section V - For the Fuel Demand Analyst

Discusses considerations important for fuel demand forecasting, and illustrates techniques for estimating past, current, and future model years' average road MPG.

Section VI - Consumer Adjustment of EPA MPG

Discusses and evaluates methods for adjusting the EPA fuel economy values for individual consumer vehicle usage characteristics.

Section VII - Public Comment

Summarizes the comments received during the preparation of this report.

II. BACKGROUND

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Modification of the EPA MPG System 23

Fuel economy figures have historically served two purposes: as input data for fuel demand forecasters, and as information for consumers.

Demand forecasters are primarily concerned with the cumulative fuel consumption behavior of all vehicles in service. They need to know, for each past, current and future model year in the fleet, the respective number of vehicles, average miles driven per vehicle, and average vehicle MPG. Individual vehicle fuel economy variances due to the multiplicity of vehicle characteristics, and driving patterns and conditions, are of lesser consequence to demand forecasting as long as the average values are known.

Consumers are concerned with relative fuel economy capability between various models, for purposes of comparison shopping, and also with information for predicting their own absolute fuel economy and fuel costs.

Recent history encompasses three distinct periods involving fuel economy information, its basis, and its uses:

- The "Free Market" period: prior to 1975;
- The "Voluntary MPG Improvement" period: 1975 through 1977;
- The "Mandatory MPG Improvement" period: 1978 and later.

In the Free Market period, vehicles' fuel economy characteristics were determined by (a) design choices made by the vehicle manufacturers in response to marketing considerations, with some influence from government safety and emission control requirements, and of course by (b) the drivers of the vehicles. The only basis for fuel demand projections was knowledge of historical trends and extrapolations of those trends into the future.

For demand forecasters, the only available MPG figure even approaching reliability was the ratio of estimated total U.S. vehicle-miles traveled[1] to estimated total gallons consumed, calculated annually by the Federal Highway Administration for the nation and for the individual states.

Those consumers who were concerned with fuel economy had to make do with promotional data (advertising) and independently derived data appearing in trade and consumer publications. The availability of such data was sporadic, and the number of "tests" for measuring fuel economy was at least as large as the number of organizations publishing "MPG figures".

A growing concern for fuel conservation was reflected in a number of events occuring between late 1972 and early 1974:

- In November 1972[2], EPA published fuel economy data from tests performed for emissions surveillance and certification of cars from the 1957 through 1973 model years;

- In an energy message to the Congress on April 18, 1973, the President called for a voluntary fuel economy labeling program for autos, along with energy-consuming home appliances. Responsibility for the auto fuel economy labeling program was assigned to EPA, in cooperation with the Department of Commerce and the Council on Environmental Quality;

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[1] Various computations of annual miles traveled differ by at least 14% and by as much as 33.5% (see U.S. Department of Energy, "Vehicle-Miles of Travel Statistics, Lifetime Vehicle-Miles of Travel, and Current State Methods of Estimating Vehicle-Miles of Travel", Oak Ridge National Laboratory Report ORNL/TM-6327, February 1979).

[2] U.S. Environmental Protection Agency, "Fuel Economy and Emission Control, November 1972.

- Responding to the President's April message, EPA published emissions certification MPG results in May 1973 for the 1973 models[3], and in November 1973 for the 1974 models[4]; protocols for the use of emissions test MPG values in the fuel economy labeling program were published in August 1974[5]. Auto manufacturers representing some 95% of auto sales in the U.S. agreed to participate in the program;

- In an energy message to the Nation on June 29, 1973, the President asked consumers to reduce fuel consumption by five percent;

- A group of Mideast oil-producing nations imposed an embargo on oil exports to the U.S. in late October 1973;

- Auto manufacturers accounting for some 95% of U.S. auto sales agreed in early 1974 to a voluntary program to achieve--by 1980--a 40% fuel economy improvement over 1974 levels;

- In parallel with the voluntary (EPA MPG) labeling program, a **dramatic rise in fuel economy advertising claims occurred.** An extensive review of auto advertising by the Federal Trade Commission revealed that in the first three months of 1974, 61% of all auto ads made some sort of gas mileage claim, an increase of 243% over the equivalent period in 1973. In response to this concern over fuel economy advertising practices, and to a petition filed in April 1974 by Consumers Union, the FTC initiated proceedings to develop a Trade Regulation Rule pertaining to auto fuel economy promotion and advertising. In its rulemaking notice[6] the Commission said:

---

[3] Federal Register *38*, at 10868.

[4] *Ibid.*, at 30495.

[5] *Ibid.*, at 22944.

[6] Federal Register *39*, at 34382.

"...Not only had the sheer number of such claims multiplied enormously, but the specificity of the claims also rose. Advertisements in which a specific miles per gallon figure was claimed increased from 5% of the ads run in the September to December 1973 period, to 7.6%, 12.9% and 35% of those run in January, February and March of 1974 respectively.

This increase in specific claims was accompanied by a proliferation of ads in which the test method on which the claim purportedly was based was referred to or described to some degree in the advertisement. Only one advertisement citing the test method used was counted between September 1972 and November 1973, but in March of this year [1974], 35% of the automobile advertisements made some reference to a specific test method said to have generated the claimed fuel economy data.

The utility to consumers of the test information appearing in the ads is open to serious question. The tests are not comparable. Some tests used were conducted on interstate highways at or near the speed limit; others were on test tracks, at varying speeds, still others were simply termed "city", "suburban" or "highway" tests, without further description. Test drivers ran the range from professional drivers, to employees of the manufacturer, to celebrities.... Other advertisements failed to note the average speed of the car tested, or the number of stops per mile, or the degree to which the car was warmed up. The disclosures were not sufficient to enable the consumer to determine the relevance of the claimed fuel economy figures to his own likely experience with the advertised car and they confirmed that variations in the tests render comparison by the consumer of competing mileage claims impossible.

These difficulties cannot be entirely overcome solely through... independent organizations.... Consumers Union, Road and Track Magazine, and numerous other interested groups have all issued mileage reports on different automobiles which differed from advertising claims made for the autos, from one another's figures and from figures published by EPA, due to the differences in test methods.

The general confusion resulting from this state of affairs has been the subject of several recent articles in the popular press including one entitled, 'Gas Mileage: Whom Do You Believe?' in the April 1974 issue of Consumer Reports."

[Emphasis added]

The issue of fuel economy test methods was also examined in detail in 1974 by the Society of Automotive Engineers (SAE), the EPA, and by other segments of the Government.[7]

A. EPA MPG: A Comparison Yardstick

The net result of all these developments was confirmation of the EPA emissions test procedure as the sole official yardstick for auto fuel economy advertising, and for the voluntary fuel economy improvement and labeling programs. One of the more important considerations leading to this decision was recognition of the fact that vehicles tested for fuel economy must be verified capable of meeting emission standards--this is the only way of assuring that the MPG figures correspond to vehicles which can legally be sold in the U.S.

In this Voluntary Improvement period, demand forecasters now had a consistent basis for assigning fuel economy values to new-car fleets; toward this goal, EPA began publishing sales-weighted fleet MPG figures.[8] Forecasters also had a fixed target (1980 MPG = 1.40 x 1974 MPG) for estimating the MPG characteristics of near-term future U.S. fleets.

Consumers, too, had a consistent basis for comparing the relative fuel economy capabilities of various models tested under one uniform set of conditions. Consumers were advised that the figures came from an emissions test, and were reminded of the comparative nature of the EPA MPG figures, and of the significant effect of vehicle operation upon their own fuel economy[9]. The first EPA Gas Mileage Guide[10] pointed out:

---

[7] House Committee on Government Operations, "Conservation and Efficient Use of Energy", Report 93-1635, December 1974, at 110.

[8] U.S. Environmental Protection Agency, "A Report on Automobile Fuel Economy", October 1973.

[9] Ibid.

[10] U.S. Environmental Protection Agency, "1974 Gas Mileage Guide for Car Buyers", February 1974.

> "The EPA Test which produced this information is a suburban/urban cycle that is 7.5 miles long. It is patterned after the conditions the average driver encounters going from home to work. A dynamometer was used by professional drivers to insure that the results were scientifically accurate and comparable. In that way it is possible to make a fair comparison of fuel economy of all vehicles tested, because every vehicle was tested in exactly the same way.
>
> That does not mean, however, that you as a driver will get the same fuel economy that was obtained on our tests. There are many factors that affect the fuel economy of individual cars. For example, the length of your trip and your personal driving habits have a major impact on fuel economy.... this list is primarily useful to the new car buyer for comparisons of fuel economy of available vehicles."
>
> [Emphasis added]

1974 saw a growing concern[11] that the EPA emission test which was the basis for the Label and Guide numbers reflected only urban driving, whereas it was reported[12] that nearly 45% of annual vehicle miles accumulated by personal passenger vehicles was traveled on non-urban roads. EPA responded to these apparently valid concerns by developing a second, non-urban driving cycle[13], which was incorporated into the voluntary MPG program[14].

Beginning with model year 1975, the Labels and Guides, by this time jointly sponsored by the EPA and the DOE (then the Federal Energy Administration) included, along with the "City" MPG figure, a "Highway" MPG value.

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[11] U.S. Government Accounting Office, "Review of the Automobile Fuel Economy Testing and Labeling Program", Report to the House Conservation and National Resources Committee, August 1974.

[12] U.S. Department of Transportation, Federal Highway Administration, News Release FHwA 08-74, January 1974.

[13] Kruse and Paulsell, "Development of a Highway Driving Cycle for Fuel Economy Measurements", U.S. Environmental Protection Agency, March 1974; Austin, Hellman and Paulsell, "Passenger Car Fuel Economy During Non-Urban Driving", SAE Paper 740592, August 1974.

[14] Federal Register 39, at 36893.

[15] Public Law 94-163, December 1975.

The Mandatory MPG Improvement period began with the passage of the Energy Policy and Conservation Act of 1975[15], wherein the Congress made the Label and Guide information program mandatory, and set fuel economy standards for model years 1978 through 1985, as follows:

Model Year 1978 ...... 18.0 miles per gallon
1979 ...... 19.0 miles per gallon
1980 ...... 20.0 miles per gallon

1985 and thereafter ...... 27.5 miles per gallon

The Act specifies that compliance with these standards shall be on the basis of each manufacturer's sales-weighted corporate average combined EPA City-Highway MPG figure[16]. A third purpose for the use of fuel economy figures, namely promulgation and enforcement of fuel economy standards, was thus created.

The Act directed the Secretary of Transportation to prescribe standards for 1981 through 1984, and authorized him to amend the standard for (and subsequent to) 1985 to any level between 26.0 and 27.5 MPG. In 1977, DOT set the 1981 - 1984 standards[17] at:

Model Year 1981 ...... 22.0 miles per gallon
1982 ...... 24.0 miles per gallon
1983 ...... 26.0 miles per gallon
1984 ...... 27.0 miles per gallon

and retained the 27.5 MPG standard for post-1984 models.

The chart following depicts the trends in EPA (55/45) fuel economy within the three distinct periods.

---

[16] The mileage-weighted consumption average of the EPA City and Highway figures, proportioned 55% City and 45% Highway. This composite, or "55/45" fuel economy is calculated from:

$$\text{Composite consumption: } GPM = 0.55 \times City\ GPM + 0.45 \times Hwy\ GPM$$

$$or: \text{ Composite fuel economy: } MPG = \frac{1}{\frac{0.55}{City\ MPG} + \frac{0.45}{Hwy\ MPG}}$$

[17] Federal Register 42, at 33534.

Fuel Economy Scenarios and New-Car Fleet Fuel Economy Trends
(Combined City-Highway MPG)

Model Year	Free Market	Voluntary Improvement		Targets (Standards)	Mandatory Improvement	
		(Domestics)	(Imports)		(Domestics)	(Imports)
1985				27.5 mpg		
1984				27		
1983				26		
1982		Target: 40% Improvement over 1974		24		
1981				22		
1980		(18.5)	(31.1)	20	21.2	28.2
1979		↑	↑	19	19.2	26.4
1978				18	18.7	26.8[c]
1977	(No Target)	17.2[a]	27.7[b]			
1976	↑	16.6	25.4			
1975		14.8	23.3			
1974	14.2	13.2	22.2			
1973	14.2					
1972	14.5					
1971	14.4					
1970	14.8					
1969	14.7					
1968	14.7					
1957-1967	14.9					

---

[a] 30% improvement over 1974.

[b] 25% improvement over 1974.

[c] Note imports' fleet MPG reversal in 1978, when standards replaced voluntary improvement.

In the free market environment, fleet fuel economy did not improve; the 4.6% drop from pre-1968 (pre-emission control) models to 1974 has been shown[18] to be predominantly due to increases in vehicle weight.

In the three years following the establishment of the voluntary improvement program, steady progress in average new-car EPA MPG values was clearly in evidence. By 1977, the fleet average "Combined 55/45" figure reached 18.3 MPG, a 29% increase over the 1974 level of 14.2 MPG (55/45). Thus, in terms of EPA fuel economy ratings, more than 2/3 of the voluntary 40% improvement goal had been reached by 1977, with three years remaining to the 1980 target.

Since the setting of mandatory standards, improvement in EPA MPG has continued for the U.S. domestic auto manufacturers, but has stalled for the foreign manufacturers[19]. Those manufacturers whose average fuel economy exceeds the standards can legally decrease their fleet fuel economy, as long as they still meet the standards. In terms of fuel consumption, the average fuel consumed per vehicle-mile for these manufacturers can increase, which could be considered somewhat counterproductive given the mandate for reduced fuel consumption for the entire vehicle fleet.

B. EPA MPG: An Absolute Yardstick?

Early in the voluntary improvement period, data began to emerge which suggested that passenger cars were not, on the average, achieving the EPA 55/45 numbers in actual use.

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[18] Murrell, "Light-Duty Automotive Fuel Economy... Trends through 1979", SAE paper 790225, February 1979.

[19] Of the top-selling ten foreign manufacturers, six showed downturns in estimated average MPG from 1977 to 1979:

	1977	1979
Toyota	29	24
Nissan (Datsun)	27	26
Volkswagen	29	31
Honda	36	31
Fuji (Subaru)	30	29
Fiat	24	25
British Leyland	23	21
Toyo Kogyo (Mazda)	29	28
Mercedes-Benz	19	20
Volvo	20	21

In August 1975, EPA reported[20] the results of tests on six 1975 production cars. On the average, these cars' fuel economy, when tested on the dynamometer, was within 1% of the EPA rating for their counterpart EPA certification prototype cars, but when tested on a test track, (using the same EPA driving cycles), average MPG fell short of the EPA ratings by about 6% (the average shortfall was about 7% for the City test and 5% for the Highway test). This study also confirmed that the EPA Highway ratings were achievable in actual use: every test car met or surpassed the EPA Highway MPG value in the 150-mile road trip to the test track site, when driven in adherence to the 55 MPH speed limit.

A report by West and others[21], also in August 1975, presented data from dynamometer and track tests of over 100 model year 1975 production cars from twelve manufacturers. The track tests used SAE procedures which were not the same as the EPA procedures, but the dynamometer tests employed the 1975 EPA procedures. These tests showed an average shortfall of about 8% between EPA certification car MPG and that of the production cars. All tests were conducted on vehicles that had relatively low odometer mileage, 2000 miles.

In September 1975, General Motors made available to EPA the results of a nationwide customer fuel economy survey[22], wherein some 2600 private owners of new 1975 GM cars furnished data on miles driven and gallons of fuel purchased over a nominal one-month period of vehicle use. The GM data showed an overall average MPG shortfall of about 13% from the EPA 55/45 figure. On the average, road MPG agreed almost exactly with the EPA City figure. The data also revealed very large customer-to-customer variances in MPG: for nominally identical copies of the same model, in-use fuel economy varied from 42% to 145% of the EPA 55/45 rating.

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[20] Austin, "Passenger Car Fuel Economy--Dynamometer vs. Track vs. Road", Report 76-1, Technology Assessment and Evaluation Branch, ECTD, EPA, August 1975.

[21] West, et al, "A Technical Report of the 1975 Union 76 Fuel Economy Tests", SAE paper 750670, August 1975.

[22] Unpublished data.

These observations raised serious concerns for both the fuel demand forecaster and the consumer, and resulted in the initiation or intensification of a number of investigations, in and out of the Government, to answer three basic questions:

1. Is there one number, such as a fixed percentage, for the average in-use MPG difference, that is applicable to past models and to future models, or is there a year-to-year trend?

2. What are the causes of any MPG difference?

3. What factors contribute to the wide variance observed in the in-use fuel economy of nominally identical cars, and can they be quantified in a way usable by individual drivers to better evaluate and predict their own fuel economy?

A large amount of data generated since 1975 related to the first question has been collected, systematized, and analyzed by the DOE. Interim results of their analyses of these data were reported in 1978[23] and 1979[24]. Information related to the other two questions has been gleaned from a host of sources far too numerous to list here: some in the public domain and some furnished by interested parties during the course of EPA's studies.

Sections III and IV of this report include our detailed analysis of all of these data.

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[23] McNutt et al, "A Comparison of Fuel Economy Results from EPA Tests and Actual In-Use Experience, 1974-1977 Model Year Cars", SAE paper 780037, February 1978.

[24] McNutt and Dulla, "Factors Influencing Automotive Fuel Demands", SAE paper 790226, February 1979.

Early in the course of these technical studies, it was recognized that an early, temporary modification to the presentation of EPA MPG numbers was both possible and desirable, pending the completion of the detailed analyses. Various options for this short-term measure were tendered in a Notice of Proposed Rulemaking[25], and an interim Rule[26] was promulgated in May of 1978. The interim Rule specified that--beginning with the 1979 model year and continuing until a better data base could permit a more satisfactory solution--the Label/Guide program would use only the EPA City, or "Estimated" MPG figure. The Highway and Combined 55/45 MPG figures were dropped from the MPG Information Program, although use of the Highway figure in advertising has continued. The following quotes from the interim Rule emphasize the temporary nature of this situation:

> "... this is clearly not the final action that EPA will be taking to improve the program..."
>
> "EPA believes that the action adopted for 1979...is an interim, limited action involving the continued use of one of the estimates now in use."
>
> "The action taken for 1979 is not likely to satisfy many of those who commented on the NPRM; indeed, it does not satisfy EPA in the sense that a better solution may be found for future model years."
>
> "EPA considered and still is favorably disposed to promoting a more realistic range of in-use mileage, in view of...the fact that no one value fully characterizes a car's fuel economy."

This report constitutes the primary technical basis upon which we are formulating a more permanent system. There is a good chance that the findings herein, together with continuing technical studies and administrative tradeoffs now being explored, can lead to finalization of MPG labeling Rulemakings and Gas Mileage Guide protocols for the 1982 models.

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[25] Federal Register 43, at 6817.

[26] Ibid., at 21412.

III. IN-USE DATA

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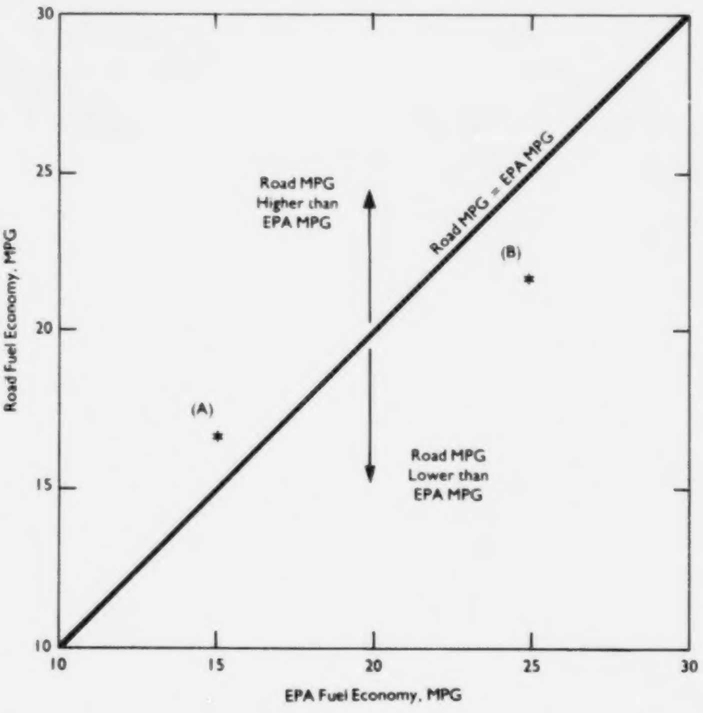
A. Methods of Data Analysis and Presentation

For much of this section, comparisons between in-use and EPA fuel economy will be presented graphically. The standard grid for these presentations is shown below. The reference EPA fuel economy is scaled horizontally, and the corresponding in-use ("road") fuel economy is scaled vertically. The grid is split by a diagonal line along which road MPG equals EPA MPG. Above this diagonal, road MPG exceeds the EPA value [as in point (A)], and below the line, road MPG is less than the EPA value [as in point (B)].

FIGURE 1. Road Fuel Economy vs. EPA Fuel Economy



For groups of cars, several treatments of the data are possible in drawing comparisons between road and EPA fuel economy; no single method is "the correct" method. Each of the treatments illustrated in the following example is used at one time or another in this report.

Consider the hypothetical group of cars listed in the table, of which three exceeded their respective EPA figures on the road, one achieved its EPA value exactly, and eight fell short of their EPA numbers.

Car	Engine	EPA MPG	Road MPG
A	4 cyl.	27	24
B	4 cyl.	26	22
C	4 cyl.	24	23
D	6 cyl.	22	21
E	6 cyl.	22	20
F	6 cyl.	21	19
G	6 cyl.	19	20
H	6 cyl.	18	16
I	8 cyl.	15	15
J	8 cyl.	14	13
K	8 cyl.	13	15
L	8 cyl.	12	13

4 cyl. subfleet:
Avg. EPA = 25.6
Avg. Road = 23.0
Difference = -10.2%
(-2.6 MPG)

6 cyl. subfleet:
Avg. EPA = 20.3
Avg. Road = 19.0
Difference = -6.3%
(-1.3 MPG)

8 cyl. subfleet:
Avg. EPA = 13.4
Avg. Road = 13.9
Difference = +3.7%
(+0.5 MPG)

Total Fleet
Avg. EPA = 18.1
Avg. Road = 17.6
Difference = -2.8%
(-0.5 MPG)

It can be seen that this fleet's average on-the-road MPG fell short of its fleet average EPA figure[27] by 2.8%. The excess fuel consumed on the road by this fleet is related to this figure:

$$\frac{\text{Road Gallons/Mile}}{\text{EPA Gallons/Mile}} = \frac{1/\text{Road MPG}}{1/\text{EPA MPG}} = \frac{\text{EPA MPG}}{\text{Road MPG}} = 1.028$$

The data can also be stratified into subsets, as in this example by engine type, and the respective in-use MPG performance of each subset examined separately. Graphically, the comparison may be presented as in the next figure, the left hand plot showing each data point, or as in one of the right hand plots, where the individual data are collapsed into:

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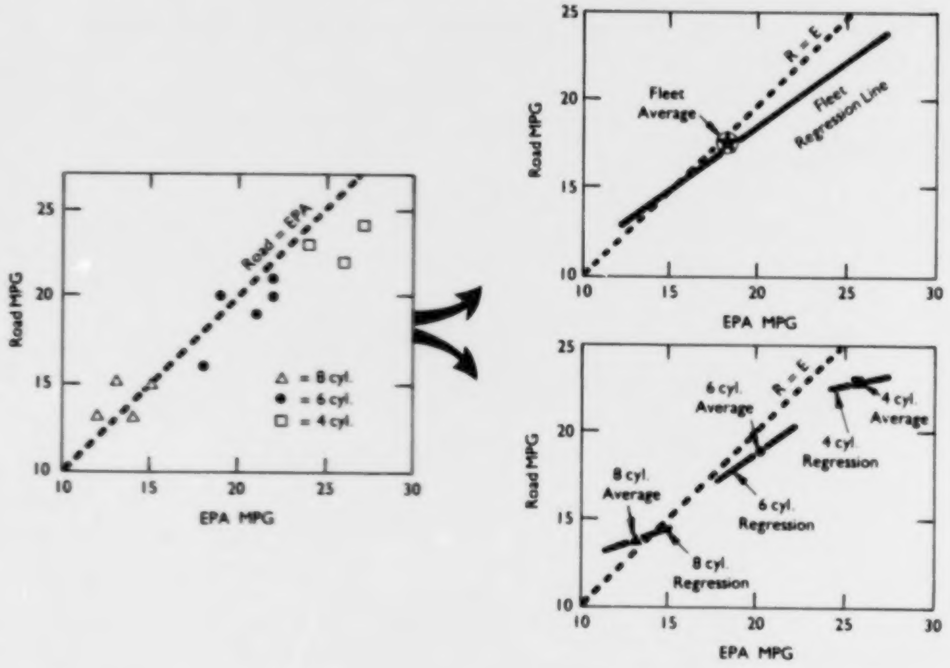
[27] The fleet average MPG figures are "harmonic" averages; See Appendix A.

one point representing the fleet, one best-fit ("regression") line through the data, or into points or regression lines representing specific subsets of data.

FIGURE 2. Examples of Data Stratification



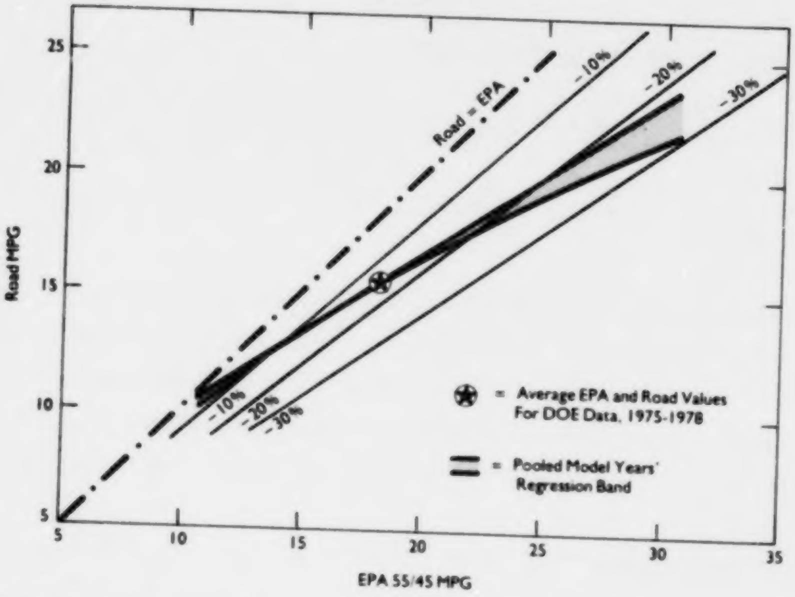
There are many options for constructing regression lines through fuel economy data (Appendix B); generally, the two types that have been adopted by DOE will be shown as the boundaries of a "regression band".

Most of the on-road fuel economy data used for this study comes from cars from model years 1975 through 1978. The primary measure of EPA fuel economy for these model years was the combined ("55/45") MPG figure and, unless noted otherwise, this is the figure referred to throughout the report as "EPA MPG".

B. Summary of In-Use Data

The graph below summarizes the road-to-EPA comparison for all of the data furnished to EPA by DOE as of early summer 1979. There is an in-use fleet MPG shortfall of 14.4% for all of the post-1974 data treated in the aggregate; fleet average EPA fuel economy for the in-use sample is 18.1 MPG, whereas these cars averaged 15.5 MPG in actual use.

FIGURE 3. Aggregate DOE In-Use Data



The average shortfall for the aggregated DOE data is worse for higher-MPG cars, not only from the standpoint of absolute MPG differential, but on a percentage basis: there is less than 10% average shortfall for cars with EPA ratings below 13 MPG, while cars with EPA ratings above 25 MPG show an average in-use MPG deficiency between 20% and 30%.

The two DOE regression equations for their 1975-1978 data set are given below; the "fuel economy" regression is seen to be a statistically better representation of the data than the "fuel consumption" regression. These two equations form the boundaries of the regression band in the previous figure.

Fuel Economy Regression:

$$MPG_{road} = 0.664(MPG_{EPA}) + 3.492$$

Correlation Coefficient (r) = .81

Fuel Consumption Regression:

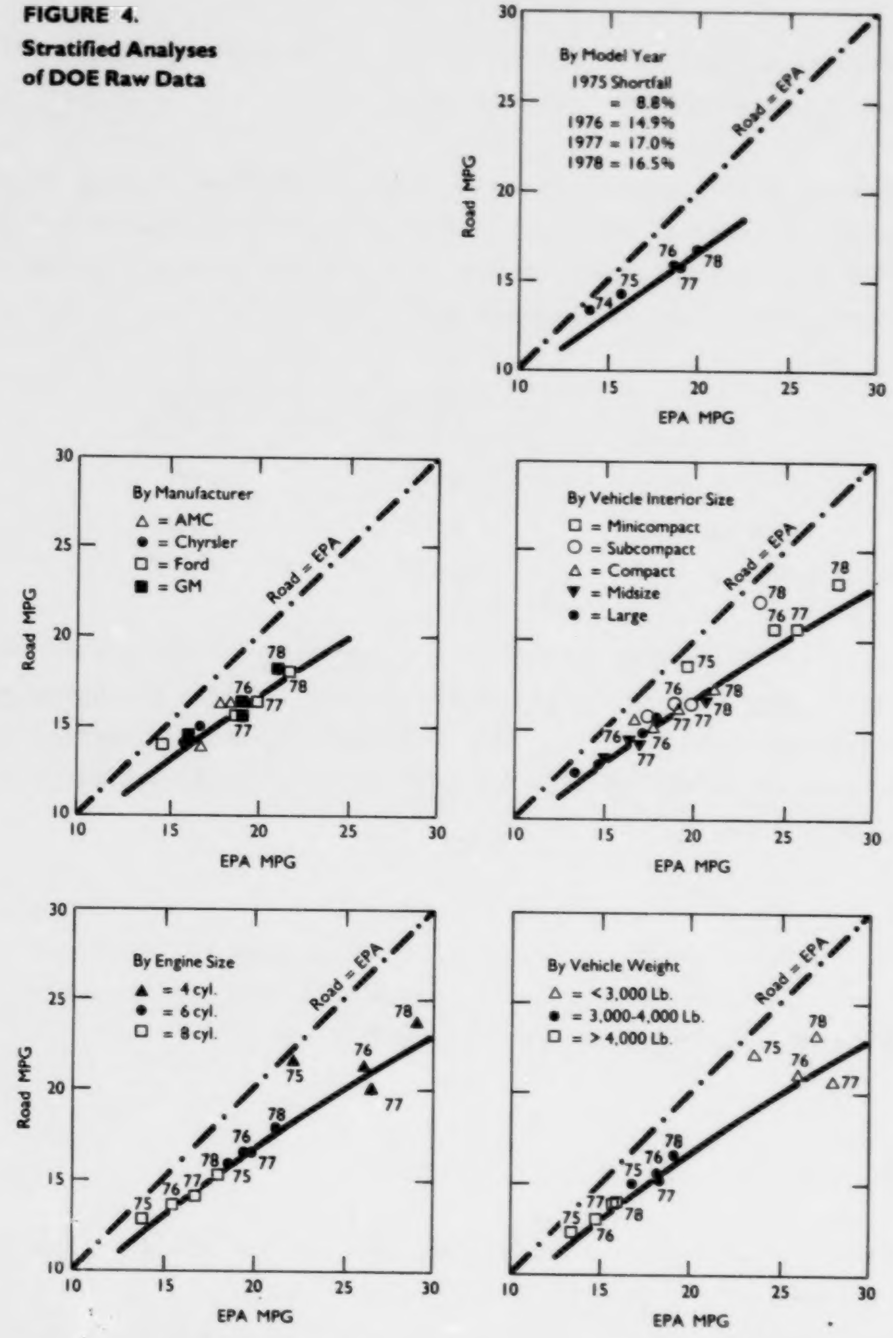
$$1/MPG_{road} = 0.878(1/MPG_{EPA}) + 0.017$$

Correlation Coefficient (r) = .76

Subdivision of the aggregate data into various strata shows results which are generally in good agreement with the regression band. This verifies that regression analysis of the total data sample (which is dominated by lower-MPG cars) does produce a curve which accurately reflects the average in-use shortfalls of higher-MPG cars.

The five-graph composite figure illustrates these stratifications.

FIGURE 4.
Stratified Analyses of DOE Raw Data



Certain findings emerge from this analysis of the raw data, essentially independent of how the data are stratified:

- There is a trend in both EPA and road MPG from 1974 through 1978, and the five-year trend is upward;

- There is a disjoint year-to-year trend in the fleet average road-to-EPA shortfall: the fleet shortfall worsened consistently from 1975 through 1977, then improved with the 1978 models. Stated another way, fleet MPG changes are:

	Change in EPA MPG	Change in Road MPG
1974 to 1976	+34%	+18%
1976 to 1977	+1.2%	-1.2%
1977 to 1978	+6.1%	+6.6%

- The disjoint shortfall trend is most apparent for the highest-MPG engine size and vehicle weight strata, wherein road MPG decreased consistently from 1975 to 1977, while EPA MPG was increasing. The average shortfall for high-MPG 1978 cars is clearly better than 1976 or 1977.

- Every subdivision of the data, whether by vehicle technical specification, manufacturer, or model year, shows some MPG shortfall on the road: every data point representing the average for each stratum falls below the road/EPA equivalence line.

C. Representativeness of the Data Sample

As pointed out above, these conclusions apply to the DOE data sample (12,000 cars), which is approximately 3/100 of 1% of the entire vehicle population on the road for these model years. In view of this relatively small sample size, the representativeness of the sample must be considered before projecting the sample's conclusions onto the total road population.

The sample is known to have three representational shortcomings:

- Imported cars are, for all practical purposes, not included in the sample, whereas imports account for some 16% of new-car sales in the U.S. for 1975-1978[28];
- The majority of the data sample consists of rental or company fleet cars, whereas fleet cars account for less than 14% of all new-car sales for 1975-1978[29,30].
- Odometer mileages are progressively higher for earlier model years, so year-to-year comparisons are not "new-car to new-car" comparisons.

1. Imported Cars

Until more road MPG data are available on imported cars, we cannot assess whether or not their exclusion biases the sample results. It must be pointed out that many of these vehicles are in the higher EPA MPG strata, and can affect the nature of the overall shortfall relationship.

2. Fleet and Consumer-Driven Cars

Regarding the disproportionately high number of fleet cars in the sample, it has been noted[31] that cars sometimes show greater shortfalls in fleet use than in consumer use.

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[28] Murrell, Op. Cit. (18), at 25.

[29] Shonka, "Characteristics of Automotive Fleets in the United States 1966-1977", Oak Ridge National Laboratory Report ORNL/TM-6449, September 1978.

[30] Bobit Publications, Automotive Fleet, April 1979.

[31] McNutt, Op. Cit. (23), at 15.

A patent example of this is the data in the following table, for a popular high-MPG Subcompact car. The "consumer use" figures come from a customer survey[32] by the manufacturer, and the "fleet use" figures from the fleet records[33] of a telephone company, as furnished to DOE. The differences between the consumer and fleet on-road MPG averages, and (especially) minimums, are quite significant. In the absence of detailed data on the usage patterns for these vehicles, one can only theorize how Subcompact cars could be operated in fleet service to produce road fuel economies less than five miles per gallon.

	1976		1977	1978
EPA 55/45 MPG	28.7		29.7	28.0
Road MPG in Consumer Use:	(Summer)	(Winter)		(Summer)
Number of Cars	20	12	-	56
Max. Road MPG	27.9	24.8	-	30.2
Min. Road MPG	17.1	15.8	-	15.3
Avg. Road MPG	21.5	20.6	-	22.7
Avg. Shortfall	25%	28%	-	19%
Road MPG in Fleet Use:				
Number of Cars	48		65	10
Max. Road MPG	25.2		31.1	26.1
Min. Road MPG	4.8		3.7	2.8
Avg. Road MPG	15.0		15.3	18.0
Avg. Shortfall	48%		48%	36%

Whatever the nature of the fleet car data, if its MPG characteristics are different from those of consumer cars, fleet car overemphasis in the sample can produce an unrepresentative picture of the actual vehicle population.

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[32] Unpublished, furnished by manufacturer.

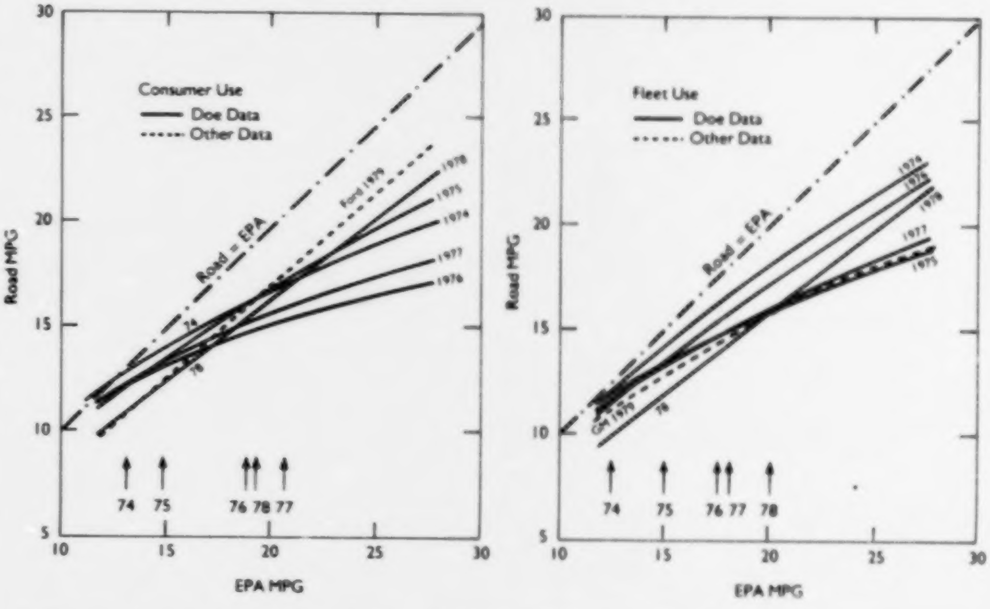
[33] Unpublished, furnished by DOE.

Fortunately, it is possible to arrive at an improved estimate of the actual population from the standpoint of consumer/fleet proportioning: DOE has provided consumer and fleet regression analyses separately, and the consumer/fleet proportions -- as a function of EPA MPG level -- can be inferred from data in the literature.

The next figure depicts DOE's consumer and fleet data through 1978, and also new data (unpublished) on 1979 models, received from Ford Motor Co. and General Motors. The consumption regression equations for all of these data are:

		Consumer Use		Fleet Use
1974	DOE:	$1/MPG_r = 0.692(1/MPG_E) + .025$		$1/MPG_r = 0.891(1/MPG_E) + .011$
1975		$1/MPG_r = 0.878(1/MPG_E) + .015$		$1/MPG_r = 0.697(1/MPG_E) + .028$
1976		$1/MPG_r = 0.601(1/MPG_E) + .036$		$1/MPG_r = 0.972(1/MPG_E) + .010$
1977		$1/MPG_r = 0.676(1/MPG_E) + .030$		$1/MPG_r = 0.794(1/MPG_E) + .023$
1978		$1/MPG_r = 1.154(1/MPG_E) + .003$		$1/MPG_r = 1.244(1/MPG_E) + .001$
1979	Ford:	$1/MPG_r = 1.251(1/MPG_E) - .004$	GM:	$1/MPG_r = 0.819(1/MPG_E) + .023$

FIGURE 5. Road Fuel Economy, Consumer and Fleet Use



The proportions of fleet cars in the total new-car population for model years 1974 through 1978 are given in the following table:

Contribution of Fleet Cars[a] to Total New-car Population

	Fraction of Cars	Fraction of Vehicle Miles Traveled (VMT)
1974[b]	12.2%	19.7%
1975[b]	11.1%	20.5%
1976[b]	11.4%	18.3%
1977[b]	13.4%	22.7%
1978[c]	12.6%	21.6%

---

[a] Fleets of 10 or more cars.

[b] Shonka, Op. Cit. (29).

[c] Bobit, Op. Cit. (30).

Because of higher average annual mileage driven by fleet cars, the VMT contribution of these cars is almost double their numerical contribution.

The next table, based on data from Bobit[30], indicates that fleets include proportionately much fewer small cars than the general vehicle population.

Car Size Differences, Fleet Cars vs. Consumer Cars (Model Year 1978, millions of cars)

	Compact or Smaller	Midsize or Larger	Small Cars, % of Total
Consumers Cars	4.5	5.9	43.2%
Fleet Cars	0.4	1.1	28.2%
All Cars (Total)	4.9	7.0	41.3%
Fleet Cars, % of Total	8.6%	15.5%	

Combining the above data and our own fuel economy and vehicle size data, the VMT proportions between fleet cars and consumer cars, by EPA MPG level, are estimated as follows:

Fleet Car %VMT/Consumer Car %VMT,
by Model Year, at Selected EPA MPG Levels

EPA MPG	1974	1975/76	1977	1978
12	26/74	30/70	32/68	34/66
16	20/28	25/75	27/73	29/71
20	15/85	20/80	23/77	24/76
24	9/91	15/85	18/82	18/82
27.5	4/96	11/89	14/86	14/86

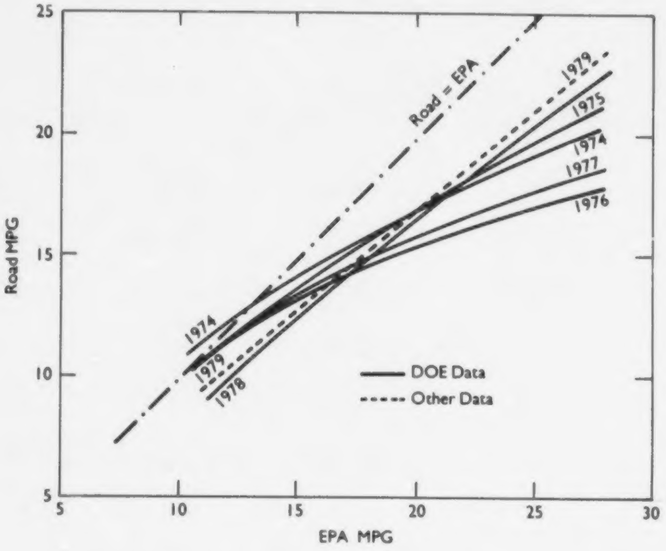
The actual population fuel economy characteristics can be derived by using road vs. EPA fuel economy values from the separate fleet and consumer regression equations, and weighting them according to the above VMT proportions. For example: in 1975, an EPA MPG value of 20 corresponds to a fleet car road MPG of 15.9, and a consumer car road MPG of 17. The relative %VMT values from the preceding table are 20 and 80, so the overall weighted road MPG is:

$$\frac{1}{\frac{.20}{15.9} + \frac{.80}{17}} = 16.8 \text{ MPG}$$

This is the road MPG value calculated for an EPA MPG of 20 in 1975.

The resulting combined fleet/consumer-weighted comparison curves appear in the next figure. The 1978 VMT weightings were assumed applicable to the 1979 consumer and fleet data. It is important to note that the 1979 curves are representative of only Ford and GM vehicles, and with the relative consumer/fleet weightings used, the consumer data (Ford) predominates. It is unfortunate that data from consumer driving of other manufacturers' 1979 vehicles are not available.

FIGURE 6. Consumer/Fleet Weighted Road MPG



3. Odometer Mileage Nonuniformities

The overall average odometer readings for the DOE data cars are estimated to be 28,800 for the 1974 models, 17,300 for the 1975's; 11,000 for 1976's; 10,300 for 1977's, and 4,000 for 1978's. The average odometer reading for the 1979 Ford data is 5,320.

Based on driver survey data[34] furnished to EPA by General Motors, larger cars accumulate mileage faster than smaller cars, the differential rate being 160 extra miles per year per 100 extra pounds of vehicle weight. These figures permit an estimate of the distribution of average odometer mileages among the model years, vehicle weights, and corresponding EPA MPG levels in the DOE data sample.

A relationship between odometer mileage and relative fuel economy has been determined by EPA[35] for dynamometer-measured EPA fuel economy.

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[34] Unpublished; also see references 50 and 51, subsequent.

[35] Murrell, Op. Cit. (18).

This relationship accounts for vehicle initial break-in, and -- for new cars, before "second car" reduced usage patterns begin to affect fuel economy -- should hold for in-use fuel economy behavior. The relationship specifically relates fuel economy at odometer mileage "M" to fuel economy at 4,000 miles, abbreviated "4K":

$$\frac{MPG(M)}{MPG(4K)} = 0.846 + 0.0186\ \ln(M)$$

where ln(M) represents the natural logarithm of "M".

All of the above combine to give the following matrix of odometer mileages and odometer adjustment factors for the in-use data; when multiplied by these adjustment factors, the in-use data are all normalized to 4,000-mile equivalent MPG values.

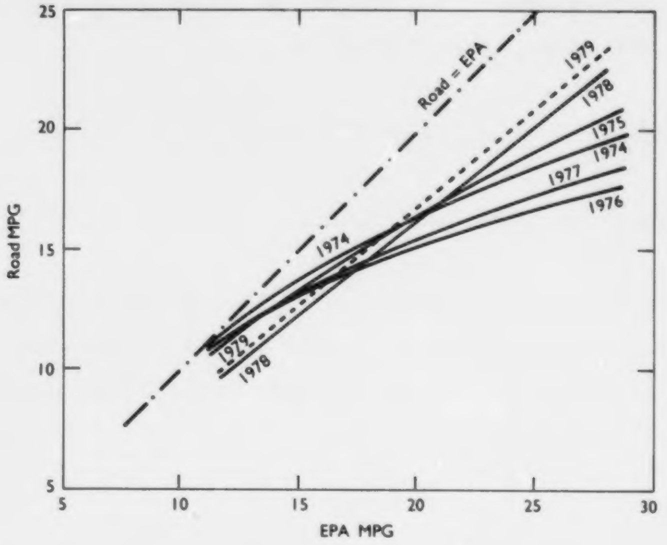
Odometer Mileage Estimates and 4,000-Mile
Adjustment Factors, In-Use Data Base

	1974	1975	1976	1977	1978	1979
EPA = 12: Odometer	30,800	19,100	12,700	12,200	4,800	6,400
4,000-mile factor	0.963	0.971	0.979	0.980	0.996	0.991
EPA = 16: Odometer	27,300	17,100	11,300	10,800	4,300	5,700
4,000-mile factor	0.965	0.973	0.981	0.982	0.999	0.993
EPA = 20: Odometer	25,900	16,000	10,500	10,000	4,000	5,300
4,000-mile factor	0.966	0.975	0.982	0.983	1.000	0.995
EPA = 24: Odometer	24,800	15,100	9,800	9,400	3,700	4,900
4,000-mile factor	0.967	0.976	0.983	0.984	1.001	0.996
EPA = 27.5: Odometer	23,700	14,600	9,400	9,100	3,600	4,800
4,000-mile factor	0.968	0.976	0.984	0.985	1.002	0.996

The odometer - corrected values are plotted in the next figure. These curves are bounded by:

(Upper) EPA MPG ≤ 20, $MPG_r = 0.599(MPG_E) + 4.614$
EPA MPG > 20, $MPG_r = 0.864(MPG_E) - 0.685$
(Lower) EPA MPG ≤ 17.5, $MPG_r = 0.856(MPG_E) - 0.544$
EPA MPG > 17.5, $MPG_r = 0.315(MPG_E) + 8.638$

FIGURE 7. Road MPG, Consumer/Fleet Weighted and Odometer Corrected to 4,000 Miles



The bounding relationships are linear equations fitted to the outer edges of the available fleet average data. As such, they should be viewed as boundaries only, and other calculations made with these curves (e.g., extrapolations to higher EPA MPG levels) should be performed judiciously. The two equations:

(High) $MPG_r = 0.864(MPG_E) - 0.685$ and

(Low) $MPG_r = 0.315(MPG_E) + 8.638$

bound the historical shortfall relationship for high-MPG vehicles. While some individual vehicles can be expected to perform outside these bounds, we would expect that future average MPG levels will fall within the bounds. With these caveats, some implications of the shortfall band can be inferred:

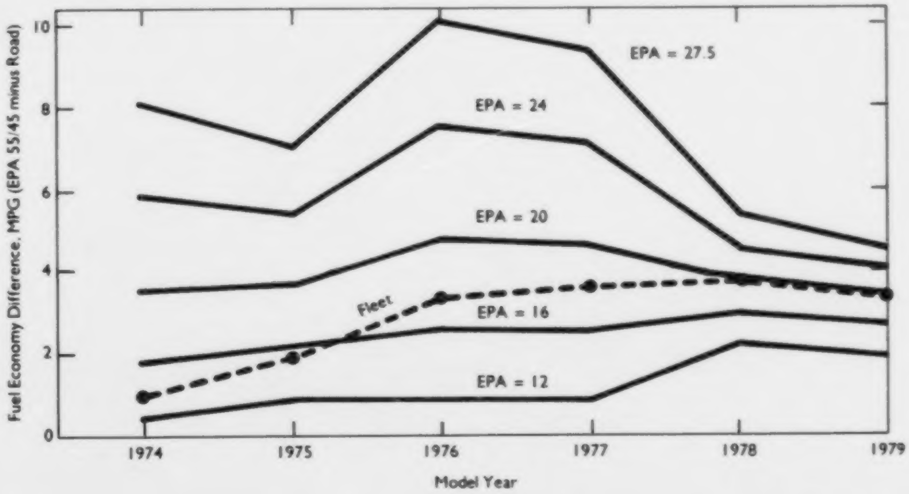
- Vehicle fleets with an average EPA fuel economy of 27.5 MPG could be estimated to average between 17.3 MPG and 23.1 MPG in actual use.
- An EPA MPG level of at least 32.6 MPG would be necessary to achieve 27.5 MPG on the road.

D. Time Trends in the MPG Shortfall

Tentative conclusions on the shortfall pattern as a function of time, or model year, were drawn earlier based on the raw data from DOE and other sources. Having adjusted these data for consumer-fleet weightings and a common odometer mileage basis, we may now draw consistent comparisons between the model years. The next figure illustrates these uniform-basis MPG shortfalls versus model year for five specific EPA 55/45 MPG levels; the shortfall for each year's entire fleet is also shown.

- ° For low-MPG cars, e.g. EPA=12 and EPA=16, there is an increasing trend in road shortfall with successive model years up through 1978, with the shortfall decreasing slightly in 1979;
- ° For the higher-MPG cars, e.g. EPA=20 and above, the road shortfall reached a maximum in 1976 and has decreased with every model year since;
- ° For the overall fleets, i.e. each year's sales-weighted combination of all EPA MPG's, the road MPG shortfall has been relatively stable from 1976 through 1979, remaining between 3.2 MPG and 3.8 MPG.

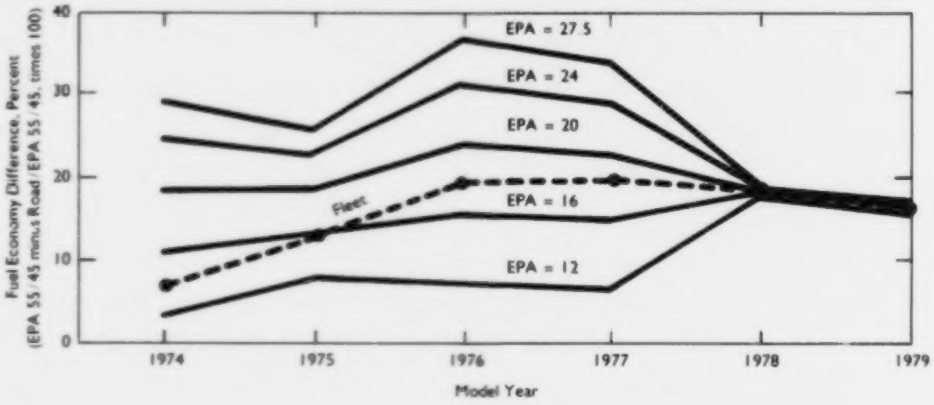
FIGURE 8. Model Year Trends in Fuel Economy Shortfalls (MPG Difference)



When these shortfall trends are viewed on a percentage basis, as shown in the next figure, the implications are similar to the above conclusions, with the additional important observation that:

- For the two most recent model years, 1978 and 1979, the percentage shortfall is very nearly constant over the entire range of EPA MPG levels, i.e. the 1978-79 models do not seem to share the "worse shortfall for higher-MPG cars" pattern seen in the 1974-1977 models.

FIGURE 9. Model Year Trends in Fuel Economy Shortfalls (Percent MPG Difference)



IV. FUEL ECONOMY INFLUENCES

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IV. FUEL ECONOMY INFLUENCES

A. Overview

Two basic potential sources of road-to-EPA fuel economy differences are the vehicles themselves, and the conditions under which the vehicles are operated in actual use. If an in-use vehicle, when tested on a dynamometer using the EPA procedures, achieves the same fuel economy as did its EPA test counterpart, there is no net vehicle-related MPG slip[36]; any road MPG shortfall (or overage) must then be due solely to in-use operating conditions which differ from those of the EPA tests. Conversely, if an in-use car's MPG on the dynamometer is different from the EPA test car value, some portion of its in-use MPG discrepancy is due to fuel economy performance differences between the EPA prototype test car and the in-use vehicle as brought in for testing.

We have chosen to apportion the "overall slip" into two parts which are defined as "vehicle slip" and "road slip". The definitions are given below:

$$\text{Overall Slip} = \frac{\text{In-use Car Road MPG}}{\text{EPA MPG}}$$

$$\text{Vehicle Slip} = \frac{\text{In-use Car Dyno MPG}}{\text{EPA MPG}}$$

$$\text{Road Slip} = \frac{\text{In-use Car Road MPG}}{\text{In-use Car Dyno MPG}}$$

Note that overall slip equals vehicle slip multiplied by road slip.

The data supplied by DOE included information on dynamometer tests of in-use cars, from which "vehicle slip" can be evaluated, and on road MPG of in-use cars that had also been dynamometer-tested, from which "road slip" can be evaluated. The DOE data cover model years 1975 - 1977.

---

[36] "slip" is used herein in the neutral sense: it can be either upward or downward.

The tables below summarize the DOE data. Whether analyzed in terms of fuel economy or fuel consumption, each model year shows some shortfall due to vehicle slip, and an always-larger shortfall due to road slip. It can be concluded from these data that about 2/3 of the observed in-use fleet shortfall is due to vehicle operating conditions, with the remaining 1/3 attributable to the in-use vehicles themselves.

Vehicle Slip, DOE Data
(Approximately 4000 Cars)

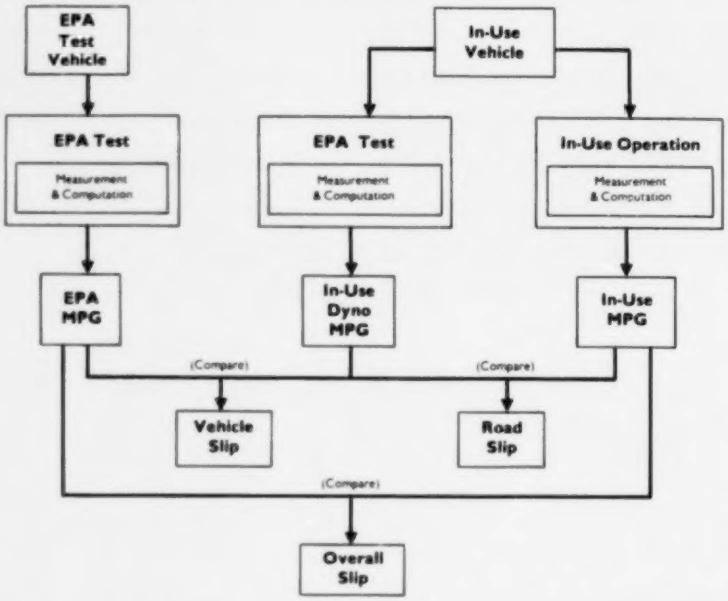
	EPA MPG	In-Use Car MPG (Dyno Tests)	Vehicle Slip
1975 - Economy Average	16.5	16.2	.98
- Consumption Average	15.4	15.1	.98
1976 - Economy Average	19.8	18.5	.93
- Consumption Average	18.5	17.5	.95
1977 - Economy Average	19.5	18.3	.94
- Consumption Average	18.9	17.5	.93

Road Slip, DOE Data
(Approximately 400 Cars)

	In-Use Car Dyno MPG	In-Use Car Road MPG	Road Slip
1975 - Economy Average	15.5	14.2	.92
- Consumption Average	14.9	13.7	.92
1976 - Economy Average	17.7	15.9	.90
- Consumption Average	16.9	15.1	.89
1977 - Economy Average	16.7	14.7	.88
- Consumption Average	16.1	14.5	.90

On a fleet basis as shown, the data suggest that road slip was relatively constant over these three years (a reasonable possibility), but that vehicle slip may be growing worse with time (a disturbing possibility). Having introduced the concepts of vehicle slip and road slip above, component elements of those slip factors can be identified. The next diagram illustrates the hardware and operational influences on EPA and in-use MPG.

FIGURE 10. Vehicle Slip, Road Slip, and Overall Slip


EPA Test Vehicle
In-Use Vehicle
EPA Test
Measurement & Computation
EPA Test
Measurement & Computation
In-Use Operation
Measurement & Computation
EPA MPG
In-Use Dyno MPG
In-Use MPG
(Compare)
(Compare)
Vehicle Slip
Road Slip
(Compare)
Overall Slip

The following table lists the major elements and subelements which can cause vehicle slip. Influences which occur prior to acquisition of vehicles by their ultimate users are categorized as "production slip", and influences coming into play after acquisition are grouped together as "vehicle condition" items. The sources of credit or blame for each influence are also given.

Fuel Economy Influences
Associated with Vehicle Slip

Vehicle Slip Influence	Responsibility
a. Production Slip	
Administrative Variance	EPA, Manufacturer
Hardware Variance	Buyer, Transporter, Dealer, Manufacturer
b. Vehicle Condition (Test)	
Engine Tune	Owner, Tuner
Engine Response to Fuel Properties	Owner, Tuner, Fuel Refiners
Sampling Bias	Owner

The next table lists factors related to road slip. Included are effects that are strictly operational, and other factors whose MPG effects are seen only on the road.

Fuel Economy Influences
Associated with Road Slip

Road Slip Influence	Responsibility
a. Travel Environment	
Ambient Temperature	Uncontrollable
Barometric Pressure/Altitude	Uncontrollable
Wind and Aerodynamics	Uncontrollable
Road Gradient	Uncontrollable, Route selection
Road Surface	Uncontrollable, Route selection
Road Curvature	Uncontrollable, Route selection
b. Travel Characteristics	
Vehicle Speed	Driver, Uncontrollable
Traffic Volume Effects	Uncontrollable, Driver
Trip Length/Vehicle Warmup	Driver
Acceleration Intensity	Driver
c. Vehicle Condition (Road)	
Wheel Mechanical Condition	Owner
Tire Pressure	Owner, Driver
Vehicle Weight Load	Driver
d. Simulation Variance	
Dynamometer Loading	EPA
Tire/Dynamometer Interaction	EPA
Weight Class Distributions	EPA, Manufacturer
Manual Transmissions	EPA, Manufacturer
Power Accessories	EPA
Vehicle Cooling	EPA
Metric Slip	EPA, Manufacturer, Owner/Driver

The elements in the preceding tables are discussed briefly below. Detailed analyses of the MPG effects of the various elements appear in Sections B and C.

1. Vehicle Slip

a. Production Slip - production slip exists if a production vehicle differs in fuel economy performance from the "vehicle" corresponding to the specific EPA fuel economy number on the EPA/DOE Gas Mileage Label and in the Gas Mileage Guide. Two opportunities for production slip occur: one associated with the vehicles in the EPA test fleet and the manner in which test results make their way into the Labels and Guides, and the other associated with the production vehicle hardware.

Test vehicles are selected nearly a year before new model introduction; the car configurations to be tested are selected based on several factors, among them the auto manufacturers' intended model offerings and estimated sales distributions. For a given model, the "EPA fuel economy number" is, more often than not, the sales-weighted average for several test cars, all representing the same nameplate but differing to some extent in detail specifications. Any misassumption by either EPA or the manufacturers as to configuration selections and sales weightings has the potential for making the model MPG unrepresentative (either high or low) as an average. Moreover, every car configuration within a given model can have a specific EPA MPG value different from the average MPG published for that model.

With regard to production hardware, differences from the EPA test cars can and do result from buyer/dealer agreements on new-car specifications. As an example, if less than one-third of the cars of a given model are forecast to be sold with air conditioning, the EPA test car is not tested to simulate the MPG effect of air conditioning. Every buyer/dealer agreement to purchase an air-conditioned version of that model creates production hardware that is different from the test car. The same applies to other power-consuming accessories and a host of convenience options such as roof racks, outside mirrors and the like.

In addition, the necessity of assembling the test cars prior to new-model production, by definition, forces the use of non-production hardware in the EPA tests. The manufacturers generally assure EPA that the EPA test vehicles include only componentry representative of the expected average of the yet-to-be-built production hardware. When vehicles are actually built, transported to dealers, prepped and finally sold to customers, MPG variances are bound to occur due to the processes involved. Anything that is mass produced will show a distribution in any measurable parameter, including--for cars--fuel economy. The dispersion of this distribution and the relationship of the mean/median/mode or some other stasticial parameter to the EPA MPG value are important considerations when evaluating production slip. Resources allocated to EPA have thus far prohibited any significant post-production verification of test car representativeness. At any rate, some production cars will inevitably be inferior, and some superior, to the EPA cars simply due to tolerance stackups in manufacturing, transport, and dealer preparation.

b. Vehicle Condition (Test) - once a vehicle is in the owner's hands, a number of changes can occur which affect its fuel economy. For some of these changes, the fuel economy effect shows up in dynamometer tests of in-use vehicles: since vehicle slip is defined in terms of the dynamometer testing of in-use cars (using the EPA procedures), these changes are properly included as ingredients of vehicle slip. Other changes whose fuel economy influence appears only on the road, and not on the dynamometer, are road slip effects.

Most vehicle condition items which contribute to vehicle MPG slip are within the control of the vehicle owner. Items whose effects show up entirely in dynamometer tests include the state-of-tune of the engine; and response of the engine to in-use fuel properties.

There is also the distinct probability of a sampling bias in connection with in-use dynamometer test programs. The vast majority of testing in these programs has been and is being conducted using cars volunteered for the tests by their owners. Any malmaintained or tampered vehicles which are not being volunteered, for whatever reasons of owner reluctance, represent a thus far unmeasured source of vehicle-condition MPG slip.

2. Road Slip

a. Travel Environment - this, and the remaining MPG slip elements, relate to departures from the standard conditions specified for the EPA tests; their fuel economy effects appear in road operation. Prevailing weather and road conditions can vary over a wide range, sometimes with large effects on vehicle MPG. These factors are not generally under the control of the driver, except in the sense of route selection.

b. Travel Characteristics - the dynamics of vehicle movement have pronounced MPG influences. While somewhat dependent upon trip routes and traffic, the speed and acceleration characteristics of vehicle travel are largely a matter of driver choice and technique.

c. Vehicle Condition (Road) - Particulars of a vehicle's mechanical state which have little or no influence on dynamometer test MPG, but which do effect road MPG, include high vehicle weight loads, the mechanical condition of the vehicle wheels, and tire pressure.

d. Simulation Variance - As contrasted with in-use conditions which are clearly different from those of the EPA test, this factor refers to imprecise duplication by the test of those real-world conditions that it does attempt to simulate, primarily due to testing and facility capabilities. Where such necessary test compromises do not agree exactly with road experience, any MPG shortfall or overage would contribute to road slip. Since the measurements used to calculate EPA MPG and Road MPG are not the same, some part of the overall slip may stem from metric differences. The way in which EPA measures MPG and the way in which in-use MPG is measured can contribute to dispersion in the overall slip.

3. Vehicle Design Features

In addition to the factors described above, fuel economy is of course dependent on many aspects of vehicle design. It is pertinent to summarize here the results of MPG sensitivity studies performed on data from the 1975-1978 EPA test car fleets.

It should be pointed out that these design features are not necessarily causes of vehicle slip or road slip. Rather, an understanding of these design features is necessary to estimate the relative magnitude of various shortfall parameters in the remainder of the report.

The design factors studied were vehicle weight, engine displacement, N/V ratio[37], and transmission type; the studies consisted of comparing the fuel economies of vehicles matched in all design specifications except the one being evaluated. For weight, displacement, and N/V, the MPG dependences are expressed in terms of sensitivity coefficients:

$$S_F = \frac{\Delta MPG/\overline{MPG}}{\Delta F/\overline{F}}$$

where: S_F = percent change in MPG per percent change in the variable "F";

$\overline{MPG}$ = average MPG for the two states of the variable "F";

$\overline{F}$ = average value of F, $1/2(F_1 + F_2)$.

---

[37] N/V ratio is defined as the quotient of engine speed in rpm divided by vehicle speed in mph measured in the highest (i.e., lowest numerical ratio) transmission gear. In other words, N/V is a measure of engine revolutions per unit vehicle speed. N/V is related to rear axle ratio and wheel radius according to:

$$N/V = \frac{5280}{60 \times 2\pi r} \times \frac{Ne}{No} \times AR = 14.01 \times \frac{Ne}{No} \times \frac{AR}{r}$$

where: $\frac{Ne}{No}$ = transmission top gear output speed ratio

= 1.0 for many cars but less than 1.0 for those cars equipped with overdrive;

r = wheel radius, in feet; and

AR = rear axle ratio.

For transmission type, the MPG influence is expressed as a slip factor, the ratio of automatic transmission MPG to manual transmission MPG. For each of these design factors, an average of about 90 comparisons were made for each of the four model years, with an average of about five cars involved in each comparison. Therefore, each sensitivity coefficient and transmission slip factor is based on the behavior of some 1800 cars.

The four-year fleet average sensitivity factors (sample-weighted) are listed below, in order of decreasing EPA City MPG effect:

Average Fuel Economy Sensitivity Coefficients,
1975-78 EPA Test Cars

	EPA City	EPA Highway
Engine Displacement	-0.589	-0.578
Vehicle Test Weight	-0.388	-0.485
N/V Ratio	-0.347	-0.603
Transmission Type	0.981	0.882

The negative signs of the displacement, weight, and N/V coefficients indicate that fuel economy decreases as these design parameters increase, and vice versa. To illustrate the use of these sensitivity coefficients, a 10% increase in engine displacement causes a 10 x (-0.589) = 5.89% decrease in EPA City MPG; a 20% decrease in N/V causes a -20 x (-.603) = 12.06% gain in EPA Highway MPG. For the transmission factor, automatic transmission City MPG is 0.981 x manual City MPG, a 1.9% loss; manual transmission Highway MPG is 1/.882 x automatic Highway MPG, a 13.4% gain.

In the basic sensitivity analysis, the weight changes were accompanied by changes in dynamometer road load setting as well, so some of the observed MPG variations were due to these road load changes. Using our best current estimates of MPG sensitivity to 50 mph road load, and road load sensitivity to weight, the MPG sensitivity to weight changes alone can be determined.

These values are given below.

Sensitivity Effects of Weight and
50 mph Road Load Horsepower

	EPA City	EPA Highway
Sensitivity of MPG to $RLHP_{50}$	-0.163	-0.330
Sensitivity of RLHP to Weight	$S=0.642-3.93(10^{-5})IW$	
Sensitivity of MPG to Weight	-0.311	-0.319

The studies did not reveal any consistent patterns with respect to individual manufacturers, i.e. no specific manufacturer's cars were found consistently more sensitive to any of the design factors than those of other manufacturers.

Similarly, no significant trends in the sensitivities were found as a function of model year, with one notable exception: manual transmissions' apparent superiority over automatics for the EPA City test have been growing consistently. In 1975, there was no average manual-to-automatic City MPG difference; in 1976, manuals' City MPG was an average of 1.1% better, in 1977 3.1% better, and in 1978 3.4% better. This is believed to relate to changing specifications for shift point scheduling of the manuals, and will be discussed in a later section.

These sensitivities are not constant across the range of the design variables in the fleet. Linear regressions were run on the MPG sensitivity of each variable with respect to itself, and transmission slip was regressed against vehicle weight. As shown in the next composite figure, vehicles with larger engines are more sensitive to displacement changes, heavier cars are less sensitive to weight changes, cars with higher N/V ratios (typically the smaller cars) are much more sensitive to N/V changes, and smaller cars show greater automatic transmission MPG losses relative to manuals.

FIGURE 11(a). MPG Sensitivity to Engine Displacement

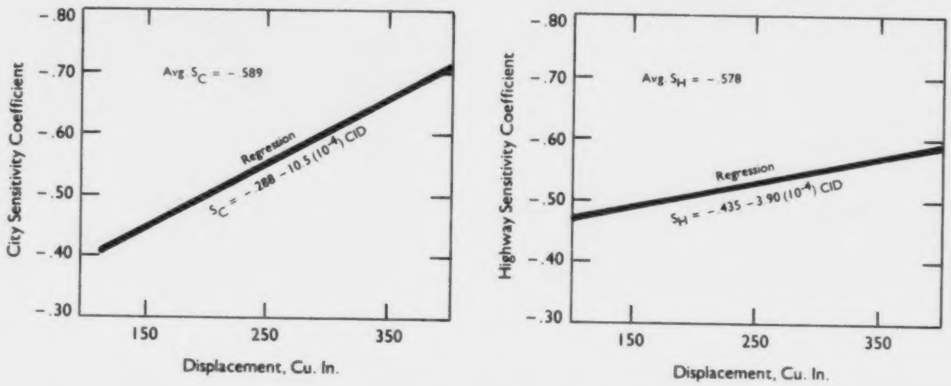


FIGURE 11(b). MPG Sensitivity to Vehicle Weight

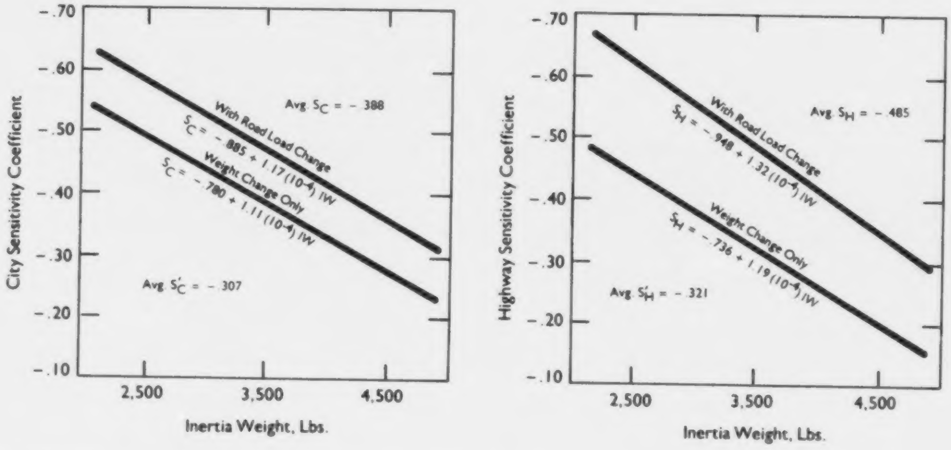


FIGURE 11(c). MPG Sensitivity to N/V Ratio

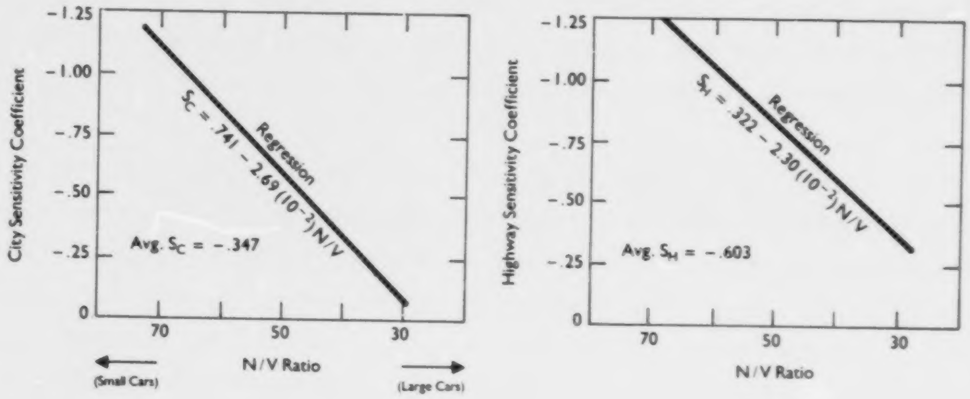
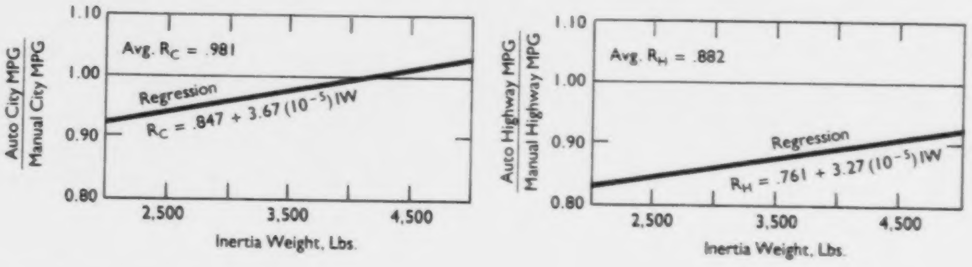


FIGURE 11(d). MPG Sensitivity to Transmission Type



4. Technical Summary

In the body of this report, the fuel economy influences identified in Section 2. above are examined, arriving at quantitative estimates of their MPG effects. This Technical Summary pulls together the results of these separate analyses, serving as a preview and also as an illustration of the influences' relative and cumulative magnitudes.

In the next two tables, two MPG effects are listed for each influence: the estimated fleetwide MPG effect, i.e. the average effect of that influence on all cars combined; and an "example" individual car effect. In other words, the fuel economy effect of an ambient temperature example value of 20°F, on a typical individual car exposed to that specific temperature, is listed as a 13% MPG loss; the fleetwide effect of all temperatures, as distributed year-round among all cars, is listed as a 5.3% MPG loss.

The conditions of the "EPA 55/45" combined test are the reference values for these analyses: where a condition is the same as the EPA combined test, there is by definition no MPG effect. The example conditions were chosen somewhat arbitrarily: there can be other values for each influence different from these example values, some better for fuel economy, some worse.

Fuel Economy Effects of Vehicle Slip Influences

Influence	Fleetwide Effect	Relative MPG	Example Effect	Example Basis
Production Slip:				
Administrative variance	-0.1%	0.999	±15%	3σ car
Hardware variance	-1.5%	0.985	±25%	3σ car
Vehicle Condition (Test):				
Engine tune	-1.0%	0.990	+10% -25%	3σ car
Engine/fuel response	-2.3%	0.977	+ 2% - 8%	3σ car
Brake drag[a]	-0.2%	0.998	- 2%	Estimated
Wheel alignment[a]	-0.1%	0.999	- 1%	Estimated

---

[a] Drive wheels only (those in contact with dynamometer rolls).

Fuel Economy Effects of Road Slip Influences

Influence	Fleetwide Effect	Relative MPG	Example Effect	Example Basis
Travel Environment:				
Temperature	-5.3%	0.947	-13%	20°F.
Altitude	- 0.1%	0.999	+ 2%	5000 feet.
Wind	-2.3%	0.977	- 6%	20 mph wind (360°).
Road gradient	-1.9%	0.981	-25%	7% grade (up/down).
Road surface	-4.2%	0.958	-25%	Several possibilities.
Road curvature	-0.1%[a]	0.999	-25%	1000°central angle/mile.
Travel Characteristics:				
Trip length	+0.8%	1.008	-10%	Four-mile trip.
Average speed	+10.6%	1.106	-15% -25%	20 mph vs 27 mph stop & go. 70 mph cruise vs 55 mph.
Cold start	-0.7%	0.993	-15%	Four-mile trip.
Acceleration intensity	-11.8%	0.882	-20%	"Hard" vs "Easy" accel.
Vehicle Condition (road):				
Brake drag[b]	-0.3%	0.997	- 5%	Estimated.
Wheel alignment[b]	-0.3%	0.997	-10%	½ inch misalignment.
Tire switching	-0.4%	0.996	- 4%	Radial ⇒ non-radial.
Tire pressure	-3.3%	0.967	- 6%	15 PSI vs 26 PSI
Weight load	-0.4%	0.996	-20%	Towing camping trailer.
Simulation Variance:				
Dynamometer load	-2.7%	0.973	-15%	50% underload at 20 mph.
Tire effects	-5.1%	0.949	- 9%	Non-radial.
Weight classification	-1.0%	0.990	- 5%	Misclassified by 1 class.
Manual transmissions	-1.8%	0.982	- 7%	Four-year average shortfall.
Power accessories	c	1.000	- 9%	Air conditioning, 90°F.
Vehicle cooling	c	1.000	c	-
Metric slip	c	1.000	- 4%	Estimated.

---

[a] Minimum penalty; probably worse

[b] Non-drive wheels

[c] Too close to call

As shown in Sec. IV.A, the average measured vehicle slip from all available in-use data sources is approximately -5%, so our accounting of vehicle slip influences is quantitatively reasonable. Average measured road slip is approximately -10%, making a calculated cumulative road loss of 27.5% appear overly pessimistic. We expect that most readers, upon examination of the analyses, will not find our estimates to be pessimistic by a factor of three across the board; instead, we conclude that the multiple fuel economy influences seen on the road do not combine simply as in the calculation above. Admitting to a bit of far-fetchedness, we might offer two analogies: that of two harsh liquids, and acid and an alkali, combining to produce not a doubly destructive liquid but a relatively benign saline solution; or that of two 60 decibel noises combining into not a 120 decibel noise but one of 63 decibels. The subject of combined MPG influences is discussed briefly in a later section; this area in itself needs considerable additional study.

Model year differences were investigated for some of the fuel economy influences, and are listed in the next table. These may not be the only effects with year-to-year variation; however, the yearly cumulative effect of these items does parallel the overall fleet shortfall trends shown earlier (Section III.D.).

Model Year Trends in Certain MPG Influences

	Model Year:					
Influence	1974	1975	1976	1977	1978	1979
Administrative variance	--	+1.3%	-1.1%	-1.6%	+0.9%	--
Hardware variance	+0.6%	-7.5%	-8.0%	+3.3%	+1.4%	+1.2%
Tire type malsimulation	--	-2.0%	-1.8%	-1.7%	-1.6%	a
Weight classification	(-1.0%)[b]	(-1.0%)	(-1.0%)	-1.0%	(-1.0%)	(-1.0%)
Manual transmissions	--	+0.1%	-1.0%	-1.9%	-2.5%	a

---

[a] Simulation variances reduced or eliminated in the 1979/80 EPA test procedures.

[b] Only Model Year 1977 analyzed; other 1974-1979 years believed to be similar.

FUEL ECONOMY INFLUENCES (Cont'd.)

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B. Vehicle Slip

The subject of vehicle slip has been under study within EPA since 1976. Eleven significant sources of in-use vehicle dynamometer test data which have been reviewed are listed below. Some of these sources are also included in the DOE data base.

Vehicle Slip
Data Analyzed and Model Years Covered

	1974	1975	1976	1977	1978	1979
EPA Emission Factors	X	X	X			
California Assembly Line	X	X	X			
DuPont Fleet	X	X	X			
Mobil Oil Co. Fleet	X	X	X	X		
Southern Calif. Auto Club		X				
Union Oil Co. Tests		X				
EPA Dynamometer vs. Track		X	X			
EPA Restorative Maintenance		X	X	X		
General Motors Tests			X	X	X	
EPA Subcompact Car Tests				X		
EPA Selective Enforcement Audit				X	X	X

1. Sources of Vehicle Slip Data

a. EPA Emission Factors Program - Under the Clean Air Act, EPA is responsible for surveying air pollution sources and quantifying their emission characteristics. The resulting emission factors are published by EPA for emission source inventorying, leading to the development of regional air quality models and control strategies. Administered by EPA's Emission Control Technology Division in Ann Arbor, Michigan, the EPA Emission Factors Program involves testing of privately-owned cars using the same dynamometer test procedures as are used for EPA's emission certification and fuel economy labeling programs.

The tests are conducted under contract by independent test labs in a number of metropolitan areas; the data analyzed came from the fiscal year 1974 and 1975 EF programs, in which tests were conducted in Los Angeles, Phoenix, Denver, Chicago, Houston, St. Louis, and Washington, D.C.

The test fleet for each of the sites comprises essentially the same mix of model years and vehicle configurations. All of the test vehicles are privately-owned, and are tested in the as-received condition. Most models are represented by more than one test car. The size of this data set is as follows:

Model Year	Number of Vehicles			Number of Model Configurations
	Domestic	Import	Total	
1974	424	87	511	165
1975	798	191	989	355
1976	490	107	597	194

The figure below is an example of the data for one of the more "well-populated" vehicle configurations. The graph shows the fuel economy values plotted against odometer mileage, and a linear regression line through the data. The harmonic mean MPG for the set is also shown, as is the EPA certification MPG.

FIGURE 12. Example of EPA Emission Factors Program Fuel Economy Data

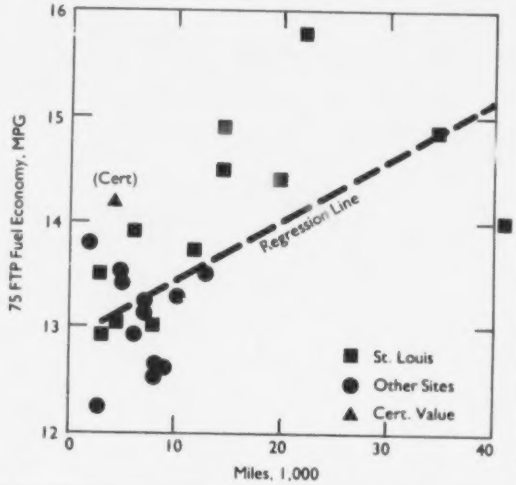
MANUFACTURER	DIVISION	CID	WEIGHT	CARB	TRANS
[redacted]	[redacted]	350	4000	2	1

TOTAL NUMBER
24

HARMONIC AVERAGE-
URBAN FUEL ECONOMY
13.5

Cert Family: 10J23
Cert MPG = 14.18

VIN	VEH#	SITE	MILEAGE	URBAN
1S87H5N56	5250	CHIC	7699	12.6
1C29H5R43	5266	STLO	14206	14.5
1D37H5B43	5254	CHIC	6870	13.1
1D37H5D41	5020	STLO	34843	14.8
1H57H5R47	5257	STLO	5984	13.9
1C29H5R46	5018	STLO	11592	13.7
1Q87H5N60	5249	STLO	2845	12.9
1H57H5A51	5252	HOUS	2259	12.2
1H57H5R44	5253	HOUS	6941	13.2
1H57H5K40	5262	STLO	21953	15.8
1H57H5R50	5255	CHIC	1439	13.8
1D37H5B40	5266	CHIC	9744	13.3
1S87H5N53	5259	STLO	19814	14.4
1H57H5K41	5255	STLO	2714	13.5
1H57H5K41	5252	CHIC	7785	12.5
1Q87H5N59	5254	STLO	4138	13.0
1D37H5R45	5018	HOUS	8455	12.6
1D29H5R48	5252	STLO	14343	14.9
1C37H5R42	5018	CHIC	4756	13.4
1S87H5N55	5249	CHIC	4717	13.5
1S87H5N59	5249	HOUS	5677	12.9
1H57H5B45	5253	STLO	7818	13.0
1H57H5B49	5018	WASH	12517	13.5
1D37H5R43	5019	STLO	40900	14.0



b. California Assembly Line Tests - The California Air Resources Board (CARB) program for assembly line testing of production cars, authorized under Title 13 of the California Administrative Code, has as its objective the emission testing of new vehicles, with primary attention given to those engine families which just barely meet the California emission levels in emission certification tests.

The cars are tested new, prior to being put into everyday use; but are not literally right off the assembly line: the CARB permits each manufacturer to specify the mileage accumulation it considers necessary to overcome "green engine" emissions variability, and pre-test mileage is accumulated using a CARB-approved durability driving schedule. The manufacturer-specified mileage accumulation schedules vary from 20 to 120 miles, so the cars are still quite new compared to certification EPA prototype cars, which are aged 4000 miles prior to the EPA tests.

The California Title 13 data base covers 270 cars, as follows:

	Number of Vehicles			
Model Year	Domestic	Import	Total	Number of Model Configurations
1974	59	5	64	31
1975	94	30	124	50
1976	79	3	82	41

The test data consist of three replicate EPA City tests for each car. Highway cycle tests were not run. Minimum mileage on any test car was 31 and maximum mileage was 153.

c. DuPont Fuel Economy Fleet[38] - Since 1970, the DuPont Petroleum Laboratory annually has purchased and tested small fleets of cars to determine year-to-year changes in fuel economy and acceleration performance. Each of the 1974-76 fleets consisted of 20 to 23 cars from the four major domestic manufacturers; small, intermediate, and large cars were included, with model selection approximating the U.S. sales distribution for these manufacturers. At the time of the DuPont dynamometer tests, all the cars for each model year had been driven at least 3000 miles, and most had accumulated more than 5000 miles. All cars were tuned to manufacturer's specifications for the tests. Fuel consumption was measured gravimetrically for both the City and Highway tests, and also by the EPA exhaust carbon balance method for the City tests. Fourteen pairs of the 1974 and 1975 model test cars were also monitored for on-road fuel economy in several thousand miles of consumer use following the DuPont dynamometer tests.

d. Mobil Oil Co. Fuel Economy Tests - Similar to the DuPont tests, the Mobil Research and Development Laboratory conducts an annual test program on small fleets (up to 11) of company cars. Mobil's primary test objectives are related to vehicle driveability, octane requirements, and emission levels, but EPA City and Highway fuel economies are measured in the emissions tests. The Mobil data[39] cover 37 cars from GM, Ford, and Chrysler, plus one AMC car and three imports.

Each of the cars was driven in consumer use by a number of Mobil employees--as many as seventeen different drivers per car--and the resulting road fuel economy data recorded.

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[38] Cantwell, et al, "Demographic and Engineering Factors Affecting Gasoline Utilization", American Petroleum Institute Report 17-76, May 1976.

[39] Unpublished.

For some model years, the dynamometer tests were conducted at low odometer mileage, while for others the vehicles had been in service for several thousand miles prior to the tests.

e. Southern California Auto Club Fleet - The Automotive Engineering Department of the Club (an American Automobile Association affiliate) regularly evaluates club-owned vehicles for various aspects of technology, including exhaust emissions and fuel economy. Dynamometer tests[40] yielded carbon balance and gravimetric EPA City and Highway MPG values for 40 1975-model GM and Chrysler cars. The cars were tested as received, essentially new; average accumulated mileage was 43 miles at the time of the tests.

In-service fuel economies for 92 cars of the same configurations as the test cars were also determined.

f. Union Oil Co. Fuel Economy Tests[41] - These tests were conducted by the Union Oil Company to determine the fuel economy characteristics of many of the more popular domestic and imported car models. The models chosen for the tests were those judged most popular by Union Oil based on 1974 production figures. All cars were purchased new specifically for the test program. All were 1975 models.

Each car was broken in for a minimum of 2000 miles, and subjected to dynamometer tests using the 1975 EPA City and Highway procedures to verify that its emissions were within the levels of the 1975 emission standards[42]. Maximum mileage allowed at the start of track testing was 2100 miles.

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[40] Appleby, et al, "Comparisons of Exhaust Emissions and Fuel Consumption Characteristics--1974 and 1975 California Automobiles", SAE Paper 760581, August 1976.

[41] West, et al, Op. Cit. (21)

[42] Some cars failed to meet the standards on the first test, and had to be retuned to manufacturers' specifications and retested.

The dynamometer test data base from the Union Oil tests includes EPA City and Highway figures for each of 106 production cars: 86 Domestic and 20 Import.

Track tests were based on the SAE J1082 Road Test Procedure, which describes urban, suburban, and interstate driving cycles to be performed on a test track or road course.

g. EPA Dynamometer vs. Track Project - This was a 3-year EPA in-house test project aimed primarily at comparing the fuel economy of production cars as tested per EPA dynamometer procedures with the fuel economy they achieve when driven outdoors, on a test track, using the same EPA driving cycles. In the first phase of the project, six 1975 cars were tested at the EPA Ann Arbor lab and on the Ohio Transportation Research Center test track, using the standard EPA City and Highway cycles[43]. In the second phase[44], seven 1976 cars were tested at the same two sites, and additional tests were run to evaluate the fuel economy effects of vehicle warmup, tire type (radial vs. bias-belted), modifications of the standard EPA Highway cycle, air conditioner operation, open-windows driving, and road curvature.

Odometer mileage for the Phase I cars varied from 3700 to 12,700 and averaged 8300 miles. For the Phase II cars, it averaged 5400 miles and ranged from 3600 to 10,200.

All cars were tuned to manufacturer's specifications prior to testing; dynamometer tests included, along with carbon balance fuel measurement, the use of fuel flowmeters for direct comparison with the track tests. Each car in Phase I received single EPA City and Highway tests, at both test sites; each Phase II car received triplicate tests at both sites.

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[43] Austin, Op. Cit. (20)

[44] Unpublished

h. EPA Restorative Maintenance Program - because more than half of all 1975 and 1976 cars received in the Emission Factors (EF) program were failing at least one of the three emission standards, EPA initiated the Restorative Maintenance (RM) Program to identify possible causes of the emissions malperformance. A second objective was to quantify individual and combined impacts of maladjustment and disablement on exhaust emissions and also on fuel economy.

The 1975-76 RM cars, manufacturered by Chrysler, Ford, and GM were privately owned vehicles less than 12 months old, and were tested by independent test labs in Chicago, Detroit, and Washington D.C. The 300 1975-76 cars[45] had odometer mileages ranging from 700 to 14,800, averaging some 8000 miles. The 1977 RM program involved 81 cars[46] with 2300 average accumulated miles, tested in Denver, Detroit, and Los Angeles.

The cars were tested as received, and again after each of three progressive maintenance steps, culminating in a complete tune-up. EPA City and Highway tests, and several "short cycle" tests were performed.

i. General Motors Production Car Tests - GM furnished to EPA the results of their review of fuel economy data from several dynamometer test programs on production cars[47]. The GM data included zero-mile production line audit data as well as data on broken-in vehicles (4000 to 10,000 miles) from all five of GM's Divisions.

j. EPA Subcompact Car Test Project[48] - The purpose of this project was specifically to evaluate vehicle slip on low-mileage Subcompact cars.

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[45] Bernard and Pratt, "An Evaluation of Restorative Maintenance on Exhaust Emissions of 1975-1976 Model Year In-Use Automobiles", EPA Report EPA-460/3-77-021, December 1977.

[46] White, "An Evaluation of Restorative Maintenance on Exhaust Emissions from In-Use Automobiles", SAE paper 780082, February 1978.

[47] Unpublished.

[48] Hutchins, "An Evaluation of the Fuel Economy Performance of Thirty-One 1977 Production Vehicles Relative to their Certification Vehicle Counterparts", Report 77-18, Technology Assessment and Evaluation Branch, ECTD, EPA, January 1978.

Subcompact cars were selected because (1) with their higher fuel economies, there was greater potential for detecting any differences between production car and certification car fuel economies, and (2) higher-MPG cars had been reported as having larger in-use MPG shortfalls.

Eleven models representing the fuel economy leaders of the 1977 Subcompact class were selected. Generally each specific car selected was the fuel economy leader within that individual manufacturer's model line. Thus, the project was directed toward the highest fuel economy vehicles in the Gas Mileage Guide and was not designed to be representative of the wide range of model offerings (and fuel economies) in the Guide.

Five of the models were Domestically-produced, five were Imports, and one was manufactured overseas for Domestic retailing. For each model, two privately-owned cars and one manufacturer-furnished car were tested. All vehicles had between 3200 and 8800 miles of accumulated mileage (average 5400), and were tuned to manufacturer's specifications prior to the tests. Manufacturer representatives were invited to, and did, participate in the check-in inspection of all test cars. Triplicate runs of the EPA City and Highway tests were performed on each vehicle.

k. EPA Selective Enforcement Audit - EPA's Enforcement arm conducts a continuing program to monitor the emissions of new, very low-mileage production cars. Odometer mileages range from zero to 4,000, with most cars tested at about 100 miles. Test data[49] include single EPA City tests on multiple-car samples of individual models from GM, Ford, Chrysler, American Motors, and eight foreign manufacturers. The size of this data base is as follows:

	Number of Vehicles			
Model Year	Domestic	Import	Total	Number of Model Configurations
1977	215	-	215	20
1978	223	43	266	27
1979	219	27	246	26

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[49] Unpublished.

2. Odometer Mileage

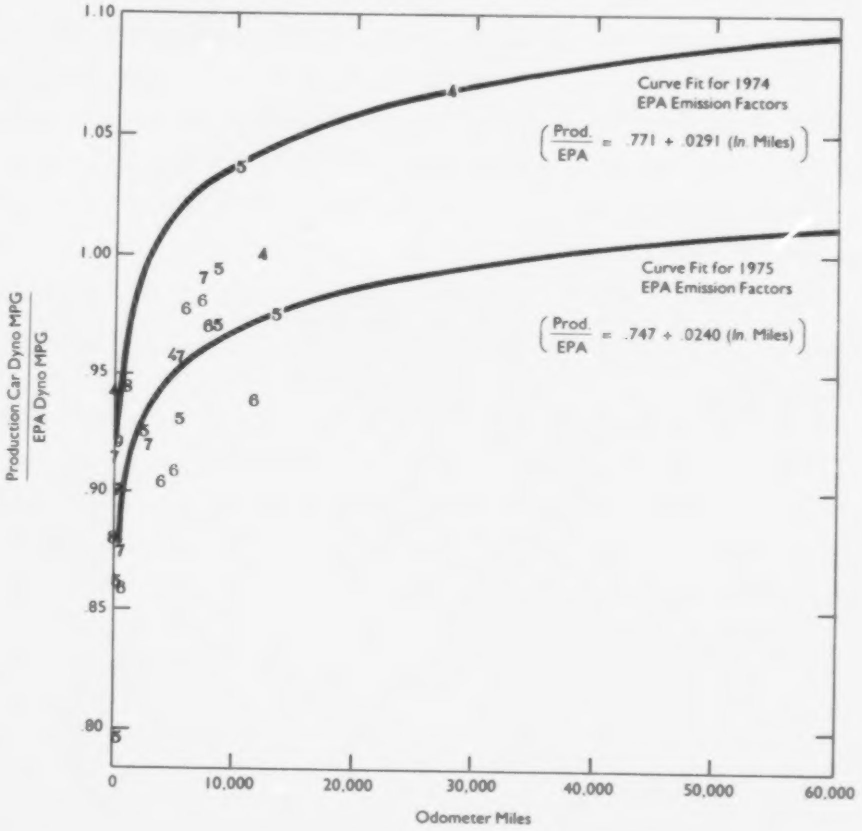
The fleet average vehicle slips for the data sources above vary considerably, from a low of .80 (a 20% shortfall) to a high of 1.06 (a 6% overage). However, the variation is not random. For instance, the lowest (worst) vehicle slip value comes from a very low mileage fleet, and the highest (best) value comes from the fleet with the highest odometer mileages. When the fleet vehicle slips are arrayed by model year, in order of increasing mileage, it becomes clear that there is a definite relation between vehicle slip and odometer mileage:

Model Year	Data Source	Average Odometer Miles	Vehicle Slip
1974	California Assembly Line	∿100	.94
	DuPont	>5,000	.95
	Mobil Oil	12,000	1.00
	EPA Emission Factors	27,400	1.06
1975	Southern California Auto Club	43	.80
	California Assembly Line	∿100	.86
	Union Oil	2,000	.92
	DuPont	>5,000	.93
	EPA Restorative Maintenance	8,000	.98
	EPA Dynamometer/Track	8,300	.99
	Mobil Oil	10,000	1.04
	EPA Emission Factors	13,300	.97
1976	California Assembly Line	∿100	.86
	Mobil Oil	4,000	.90
	DuPont	>5,000	.91
	EPA Dynamometer/Track	5,400	.98
	General Motors	∿7,000	.98
	EPA Restorative Maintenance	8,000	.98
	EPA Emission Factors	11,500	.96
1977	General Motors Audit	∿0	.88
	Mobil Oil	∿0	.89
	EPA Enforcement Audit	116	.91
	EPA Restorative Maintenance	2,300	.95
	EPA Subcompact Cars	5,400	.96
	General Motors	∿7,000	.99
1978	General Motors Audit	∿0	.88
	EPA Enforcement Audit	177	.94
1979	EPA Enforcement Audit	428	.94

The tabulated vehicle slip and odometer mileage values are depicted in the following figure. Based on the source average data points alone, one might conclude that post-1974 vehicle slip, and hence production car dynamometer fuel economy, are rising at such a rate as to double by the time some 50,000 miles have been accumulated!

Fortunately, the EPA Emission Factors data bases are large enough, and have a wide enough range of odometer mileages, to permit a more careful analysis of the odometer influence. These analyses were made for the 1974 and 1975 Emission Factors fleets, and do in fact lead to conclusions that are more palatable. The "best-fit" curves for 1974 and 1975 are drawn on the figure, and indicate that indeed there is a sharp rise in vehicle slip (and in absolute fuel economy) at very low mileage,

FIGURE 13. Relation Between Vehicle Slip and Odometer Mileage



but this rapid rate of increase is only temporary: it begins to level off above 4,000 miles. In these tests, wherein *the vehicles are all operated the same way regardless of age*, we see no evidence of a point where fuel economy peaks and declines thereafter.

The other significant finding from the Emission Factors data is that, for *any* mileage, vehicle slip is worse for the 1975 models than for the 1974's. The break-even point -- i.e., the point at which average production car MPG is equal to the EPA value -- is only 2,600 miles for 1974 models, but is not reached until some 38,000 miles for the 1975's.

3. *MPG Tilt*

Since the DOE data suggest that vehicle slip is worse for higher-MPG cars, those EPA data sources which presented car-by-car data were analyzed for this effect. Again, the results show considerable variance from source to source but here, too, we find a dependence on odometer mileage. Figure 14 shows the vehicle slip patterns for the data sources that include broken-in cars (those with odometer mileages of 4,000 or more). Individual car data points are given for two of the sources, for illustration. It will be noted that the severe MPG-level dependences inferred by some studies involving only a few cars are not fully supported by the larger EPA and DOE data bases. *All* of these sources do show *some* worsening of vehicle slip for higher-MPG cars.

In Figure 15, however, which isolates the very low-mileage cars, there is no such worsening of vehicle slip with MPG level -- with the exception of the 1974 California Assembly Line and 1978 EPA audit data. It thus appears that the "MPG tilt" in vehicle slip is a phenomenon that appears only after vehicle break-in.

FIGURE 14. Vehicle Slip vs. EPA MPG

Data Sources with 4,000 or More Odometer Miles

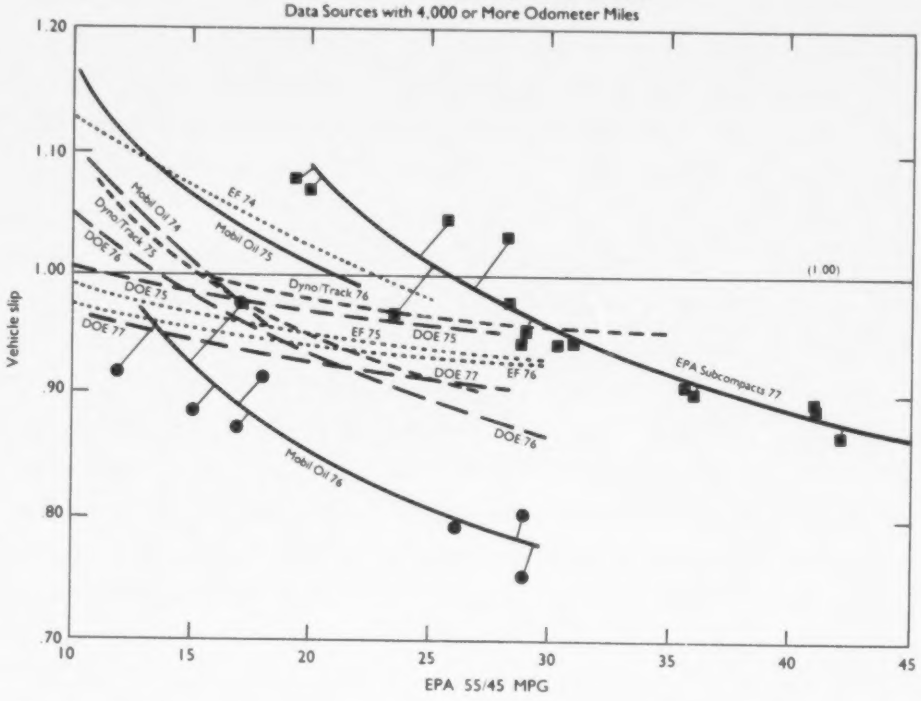
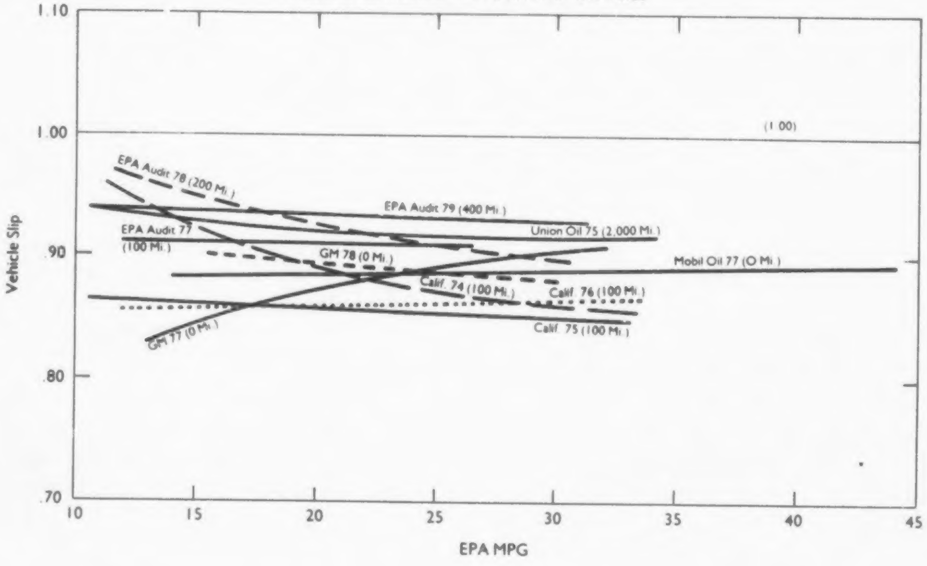


FIGURE 15. Vehicle Slip vs. EPA MPG

Data Sources with Less than 4,000 Odometer Miles



Now, there are certain known operational and maintenance differences[50,51] between cars, as a function of vehicle and/or engine size, which can affect fuel economy after break-in. These differences also correlate with MPG level, since car and engine sizes are closely related to fuel economy. However, these observations do not fully explain the vehicle slip behavior of the specific data sources discussed above.

It is also well known that automatic transmissions predominate among the larger, lower-MPG cars, while manual transmissions are more common to the smaller, higher-MPG cars. If cars with manual transmissions characteristically had worse vehicle slips than those with automatics at the same EPA MPG level, this shift in transmission mix would handily explain the MPG tilt in vehicle slip. Our analysis of the 1974-76 Emission Factors data and the 1977 Subcompact car data, however, show that it is the automatics which generally have worse vehicle slips, as illustrated in Figure 16. If anything, the transmission mix shift would have the effect of flattening the tilt, not of causing it.

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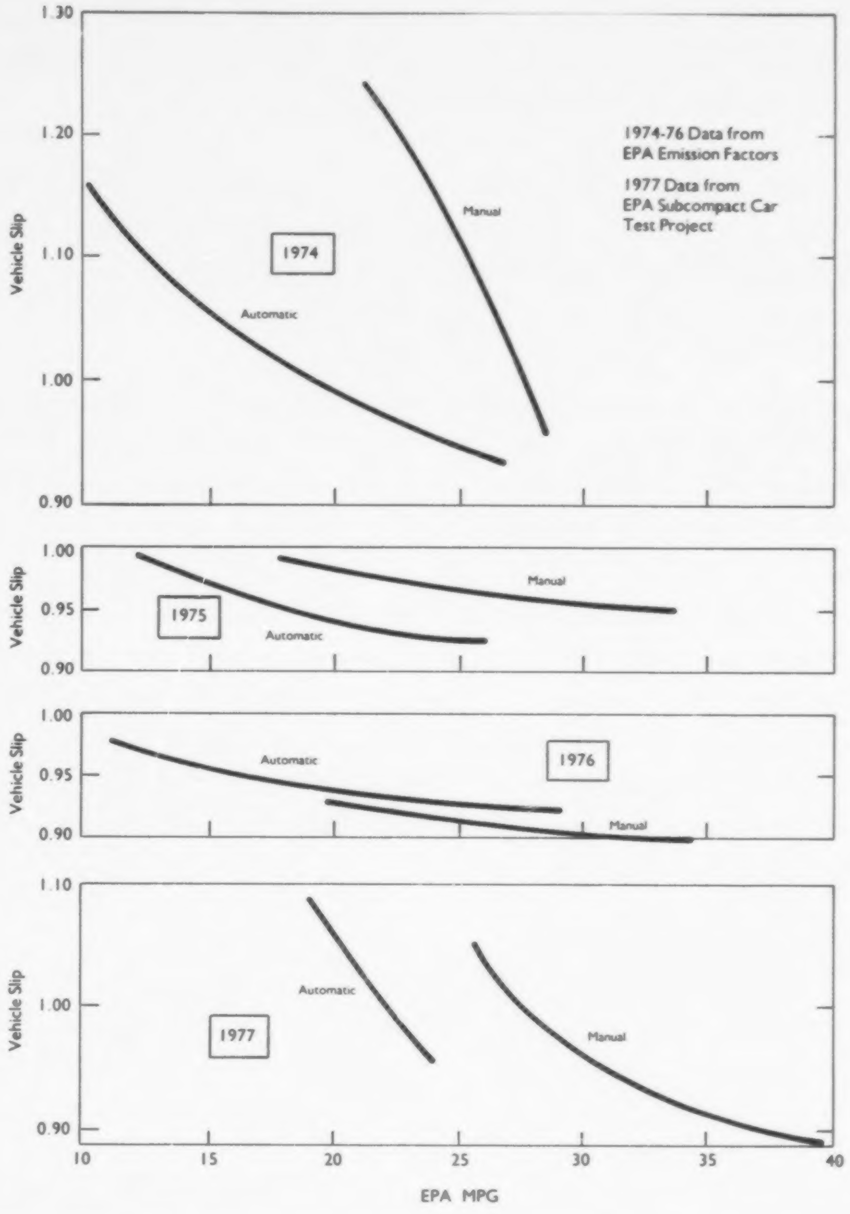
[50] A 1973 Canadian driver survey,(Canada Department of the Environment, "Canadian Automobile Driver Survey", Report EPS 3-AP-73-10, October 1973) indicates that smaller engines are tuned up more frequently than larger ones. The survey also reveals that larger vehicles accumulate more miles annually than smaller cars.

[51] The 1974-76 EPA Emission Factors data show higher average odometer readings for heavier cars. For each of these three model years, each additional 100 pounds of vehicle weight corresponds to 100 to 200 additional miles driven per year.

FIGURE 16. MPG Tilt in Vehicle Slip Factor vs. Transmission Type



Our findings on odometer mileage and MPG tilt effects are summarized below:

- Dynamometer fuel economy increases with vehicle odometer mileage, with the rate of increase being quite high at very low mileage and leveling off after 4000 or 5000 miles;

- For 1974 models, only those cars with low odometer mileages show an MPG shortfall due to vehicle slip: after some 2500 miles, the average 1974 vehicle slip rises above 1.0, i.e., average production car dynamometer MPG becomes greater than EPA MPG;

- For post-1974 models, vehicle slips (at comparable mileages) are generally worse than those of 1974 cars. However, there is no clear pattern at all that vehicle slips for post-1975 models may be continually getting worse year by year;

- Vehicle slip does not vary with MPG level (i.e., worse at higher MPG) for very new cars; MPG tilt is a phenomenon peculiar to broken-in vehicles. The various data sources examined are not in agreement as to just how strong this dependence is, but they all support the conclusion that there is some MPG dependence. The data bases containing the largest number of cars generally show less vehicle slip MPG tilt than those with only a few cars.

4. Production Slip

Any discrepancy between EPA fuel economy ratings and the fuel economy measured on newly-manufactured cars is referred to herin as "production slip". Viewing the "production" of vehicles in the broad sense, administrative factors which influence MPG are included along with influences that are strictly of a manufacturing nature.

a. Administrative Variance - Since in-use MPG shortfall analyses virtually always use the EPA/DOE Gas Mileage Guide/Fuel Economy Label MPG numbers as the comparison basis, it is important to review briefly how these numbers are generated.

Approximately a year before the scheduled start of a new model year, the vehicle manufacturers specify to EPA all of the vehicle types they intend to market, in accordance with regulations for emission certification (40 CFR Part 86). Vehicle configurations[52] to be tested for emission certification are selected on the basis of several factors, most notably projected sales volumes and design features to which emissions are sensitive. Within each group of similar configurations, for example, attention is given to selecting for test some configurations most likely to be worst-case emitters. When these cars are tested for emission certification, their EPA city MPG values are determined; in addition, EPA highway tests are run for fuel economy purposes.

Besides the emission certification vehicles, additional ("fuel economy data") vehicles are tested over both EPA cycles to further fill out the fuel economy data base. Although not official emission data vehicles, fuel economy data cars must demonstrate compliance with emission standards, including the application of emission deterioration factors.

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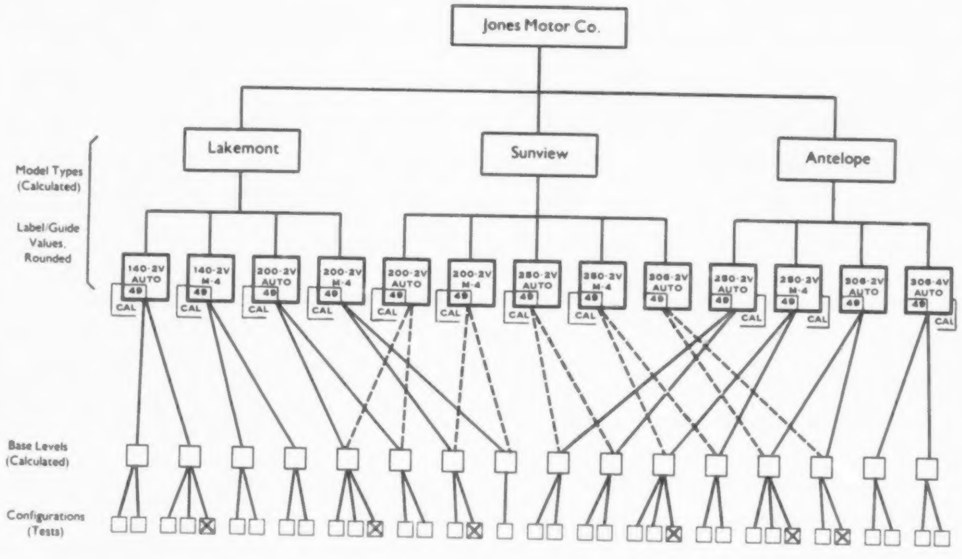
[52] A configuration is a unique combination of basic engine, engine code, inertia weight class, transmission type (manual or automatic), number of forward gears, and axle ratio; "basic engine" means a unique combination of combustion type (spark ignition, or compression, i.e. Diesel, ignition), emission standard (49 states or California), number of cylinders, displacement, fuel system (number of carburetor barrels or fuel injection), and catalyst usage; "engine code" means a unique combination of emission control system, auxiliary emission control devices, and specific set of carburetion and timing calibrations, within a basic engine; inertia weight class is the weight class to which a vehicle is assigned based on its loaded vehicle weight.

The generation of published fuel economy values from these test data proceeds according to the fuel economy regulations (40 CFR Part 600), as follows: the test data from all configurations sharing a common basic engine, inertia weight, and transmission class are combined (harmonically sales-weighted) to establish MPG values for that configuration group, or "base level"; next, the MPG values for all base levels constituting a given "model type" (combination of nameplate, basic engine, and transmission class) are combined to arrive at the MPG rating for that model type. It is the model type MPG values, rounded to the nearest whole mile per gallon, that appear on the Labels and in the Guides. The following figure illustrates the overall process schematically.

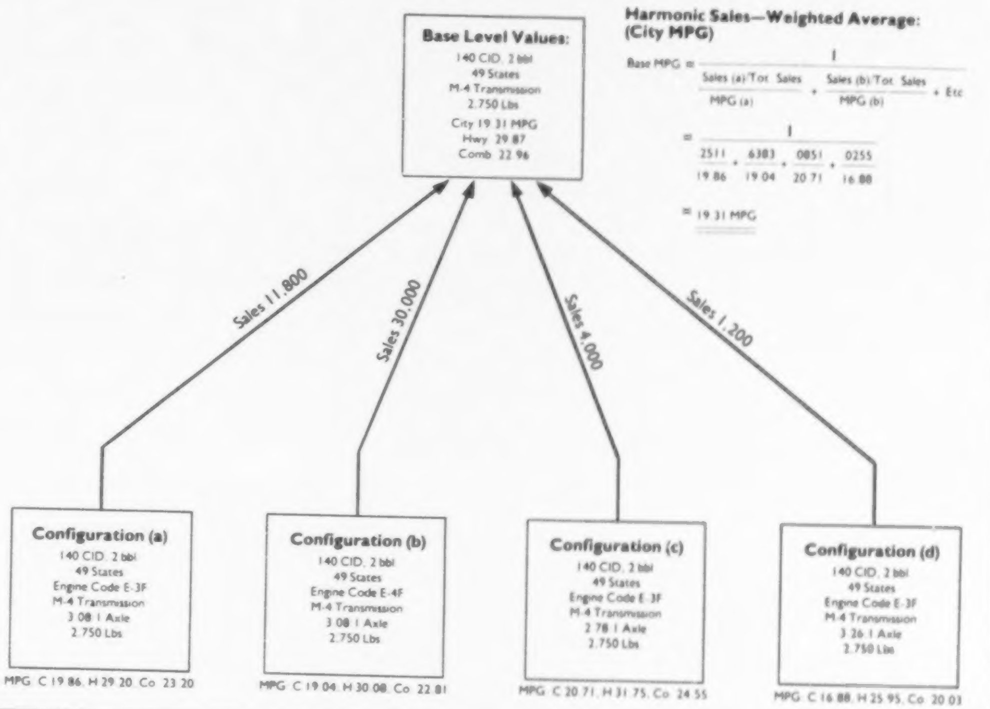
FIGURE 17. Fuel Economy Calculation Flow: from Test Data through Corporate Average


Jones Motor Co.
Lakemont
Sunview
Antelope
Model Types (Calculated)
Label/Guide Values, Rounded
140-2V AUTO 49 CAL
140-2V M-4 49 CAL
200-2V AUTO 49 CAL
200-2V M-4 49 CAL
200-2V AUTO 49 CAL
200-2V M-4 49 CAL
250-2V AUTO 49 CAL
250-2V M-4 49 CAL
306-2V AUTO 49
250-2V AUTO 49 CAL
250-2V M-4 49 CAL
306-2V AUTO 49
306-4V AUTO 49 CAL
Base Levels (Calculated)
Configurations (Tests)

(☒ = Untested)

The next figure is an example of four configurations building into a base level; the figure includes MPG values and sales volumes, and shows how they are used in the base level calculations.

FIGURE 18. Example of Configurations Combining into a Base Level


Base Level Values:
140 CID. 2 bbl
49 States
M-4 Transmission
2.750 Lbs
City 19.31 MPG
Hwy 29.87
Comb 22.96
Harmonic Sales—Weighted Average:
(City MPG)
Sales 11,800
Sales 30,000
Sales 4,000
Sales 1,200
Configuration (a)
140 CID. 2 bbl
49 States
Engine Code E-3F
M-4 Transmission
3.08:1 Axle
2.750 Lbs
MPG: C 19.86, H 29.20, Co. 23.20
Configuration (b)
140 CID. 2 bbl
49 States
Engine Code E-4F
M-4 Transmission
3.08:1 Axle
2.750 Lbs
MPG: C 19.04, H 30.08, Co. 22.81
Configuration (c)
140 CID. 2 bbl
49 States
Engine Code E-3F
M-4 Transmission
2.78:1 Axle
2.750 Lbs
MPG: C 20.71, H 31.75, Co. 24.55
Configuration (d)
140 CID. 2 bbl
49 States
Engine Code E-3F
M-4 Transmission
3.26:1 Axle
2.750 Lbs
MPG: C 16.88, H 25.95, Co. 20.03

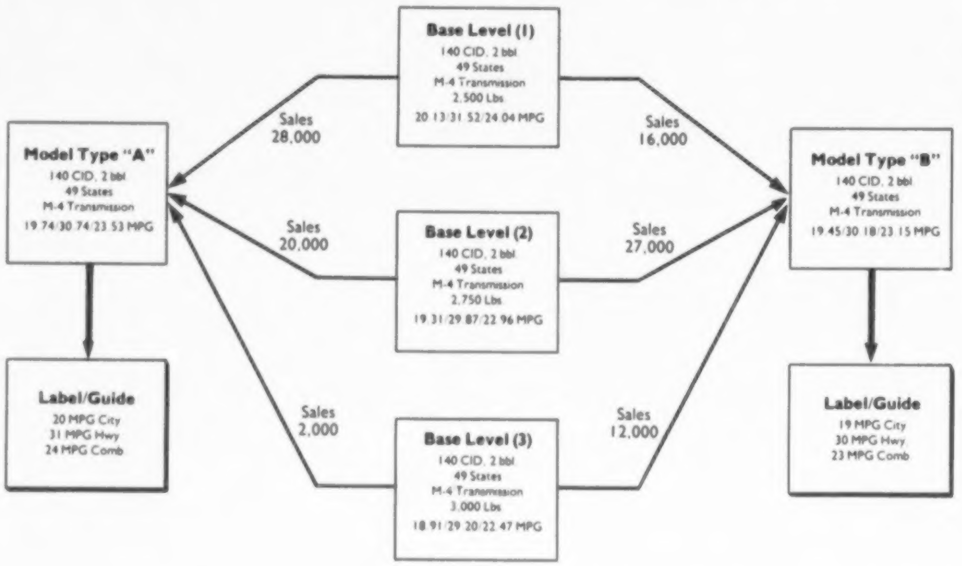
$$\text{Base MPG} = \cfrac{1}{\cfrac{\text{Sales (a)/Tot. Sales}}{\text{MPG (a)}} + \cfrac{\text{Sales (b)/Tot. Sales}}{\text{MPG (b)}} + \text{Etc.}}$$

$$= \cfrac{1}{\cfrac{.2511}{19.86} + \cfrac{.6383}{19.04} + \cfrac{.0851}{20.71} + \cfrac{.0255}{16.88}}$$

$$= \underline{\underline{19.31 \text{ MPG}}}$$

The next figure shows how three base levels, each used by two different model types (but in different sales proportions) combine to give model type MPG ratings. The rounded figures are the Label and Guide values for the two model types.

FIGURE 19. Example of Base Levels Combining into Two Model Types


Base Level (1)
140 CID, 2 bbl
49 States
M-4 Transmission
2,500 Lbs
20.13/31.52/24.04 MPG
Model Type "A"
140 CID, 2 bbl
49 States
M-4 Transmission
19.74/30.74/23.53 MPG
Sales 28,000
Sales 16,000
Model Type "B"
140 CID, 2 bbl
49 States
M-4 Transmission
19.45/30.18/23.15 MPG
Sales 20,000
Base Level (2)
140 CID, 2 bbl
49 States
M-4 Transmission
2,750 Lbs
19.31/29.87/22.96 MPG
Sales 27,000
Label/Guide
20 MPG City
31 MPG Hwy
24 MPG Comb
Sales 2,000
Base Level (3)
140 CID, 2 bbl
49 States
M-4 Transmission
3,000 Lbs
18.91/29.20/22.47 MPG
Sales 12,000
Label/Guide
19 MPG City
30 MPG Hwy
23 MPG Comb

Since the Label and Guide MPG values are determined and published very early in the model year, any changes to the configuration MPG's (via running changes or configuration deletions or additions) or variation from the sales volume forecasts can result in model type average MPG's different from the early Label/Guide values. The magnitude of any MPG slip due to such changes has not been evaluated at the model type level for prior model years. We have examined fleet level MPG changes due only to sales mix shifts (actual vs. projected) for model years 1975 through 1977[53], with the following results:

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[53] Murrell, Op. Cit. (18)

Change from Projected-sales MPG to Actual-sales MPG
(Total Fleet)

1975	1976	1977
+1.3%	-1.1%	-1.6%

These comparisons apply only to changes in the sales mix, and include the effects of sales reproportioning among the manufacturers. End-of-year Corporate Average Fuel Economy (CAFE) calculations made for compliance with the fuel economy standards will provide a much better basis for evaluating the combined slip effects of sales shifts and MPG changes, beginning with model year 1978. Our preliminary estimate of these combined effects for 1978 (with 15 manufacturers, accounting for 96% of sales, evaluated) is +0.9%. "Running changes", which can cause differences between pre-model year and post-model year fuel economy, are receiving close scrutiny in these evaluations.

Since individual consumers buy individual cars, not base levels or model types, inherent individual slips from the listed model type MPG are bound to occur. The previous examples can be used to illustrate the possible magnitude of such individual car slips. The table below lists the MPG slips for each of the four configurations in the example's base level(2), with respect to each model type that incorporates those configurations. The effect of round-off of the model type MPG is also illustrated.

55/45 Administrative Slip,
Example Base Level (2)

	Rounded Basis:		Unrounded Basis:	
	Model "A"	Model "B"	Model "A"	Model "B"
Config. (a)	.967	1.009	.986	1.002
Config. (b)	.950	.992	.969	.985
Config. (c)	1.023	1.067	1.043	1.060
Config. (d)	.835	.871	.851	.865
MPG Slip, all configs, sales-wtd harmonic	.957	.998	.976	.992
MPG Slip, Base Level	.957	.998	.976	.992

Some individual cars' EPA test MPG in this example are seen to vary from the model type average values by 10% or more. While the example is hypothetical, the assigned MPG values are not atypical.

Naturally, the sales-weighted average administrative slip for the entire set of model types is 1.0 (no average shortfall or overage), as shown in the next table.

55/45 Administrative Slip
(Model Type)

	Rounded:		Unrounded:	
	Model "A"	Model "B"	Model "A"	Model "B"
Base level(1)	1.002	1.045	1.022	1.038
Base level(2)	.957	.998	.976	.992
Base level(3)	.936	.977	.955	.971
All Base Levels	.981	1.006	1.000	1.000
	.994		1.000	

By definition, administrative slip for all model types using the same base levels must average 1.00. With some individual cars deviating from Label/Guide model type value by significant amounts (on the order of ± 10%) however, a sales shift -- or a sampling bias which overemphasizes configurations with large administrative slips--could easily create an average administrative slip of several percent in either direction for that sample.

b. Hardware Variance - A precise measure of hardware variance can come only from comparison of the dynamometer test fuel economy of new, low-mileage production cars against the low mileage MPG of those specific EPA Certification cars which exactly match the configurations of the production cars. Only in this way can the effects of mileage accumulation, vehicle modification, vehicle usage, and other post-manufacturing treatment (or mistreatment) of the cars be prevented from clouding the comparison. The following table illustrates the hardware variances, under this definition, from sources of low-mileage dynamometer test data presented earlier.

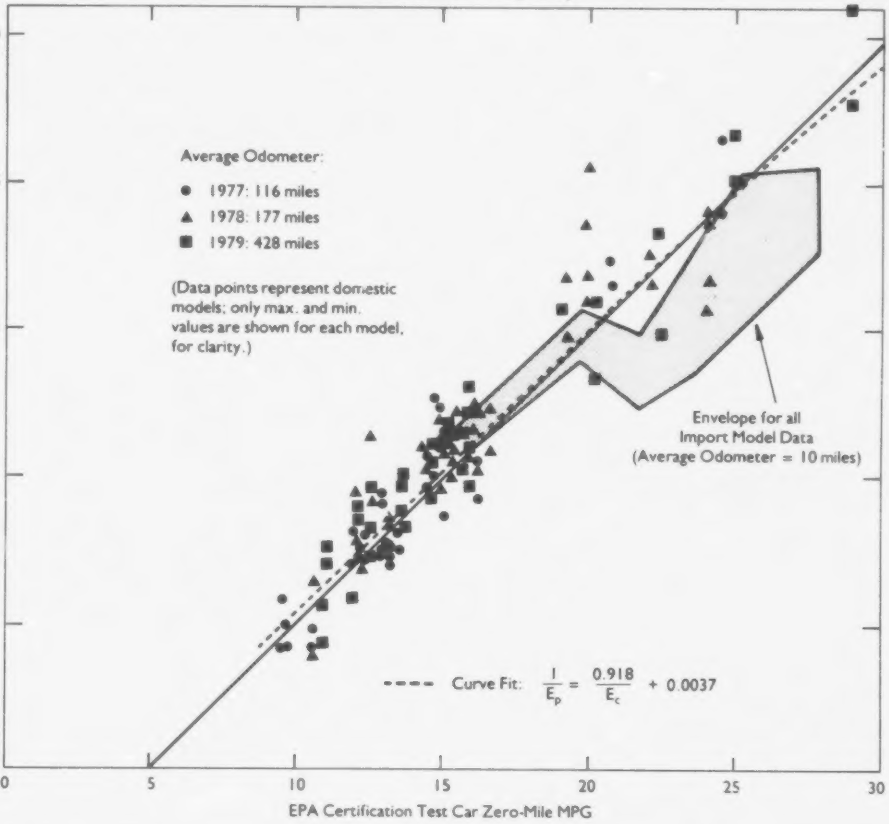
Production Hardware MPG slip, by Model year

Model Year	Data Source	Number of cars		Hardware Slip
1974	Calif. Assembly Line	64		1.006
1975	Sou. Calif. Auto Club	40	0.869	
	Calif. Assembly Line	124	0.921	
	Union Oil - Calif. Cars	13	0.924	
	1975 Average, Calif. Cars			0.909
	Union Oil - 49 States Cars	81		0.928
1976	Calif. Assembly Line	82		0.920
1977	Mobil Oil	11	0.994	
	GM Audit (8 models)	?	0.985	
	EPA Audit	215	1.037	
	1977 Average			1.033
1978	GM Audit (6 models)	?	0.984	
	EPA Audit	266	1.015	
	1978 Average			1.014
1979	EPA Audit	246		1.012

These data suggest U.S. average hardware shortfalls of about 8% in 1975 and 1976, but no hardware shortfalls for 1974 or 1977-79. Since most of the 1974-76 data are from California cars, it may not be accurate to assume that the indicated slips apply to all cars of those model years, although the 1975 non-California cars do show shortfalls comparable to the California cars.

As shown in the next figure, the EPA audit MPG's on average compare very well with zero-mile certification data for domestic cars and low-MPG imports. For imports above 20 MPG (EPA City), however, the production car data are clustered around a line some 2.5 MPG (10%) below the certification values. The consumption regression curve for all three model years is within 5% of equality with the Certification data over the entire MPG range, and lies above the equality line up to 22 MPG.

FIGURE 20. MPG Comparison: New Production Cars vs. EPA Prototypes
(EPA Audit Data, EPA City Test)



When the EPA Audit data are stratified by manufacturer, the results given in the next table are obtained. These data reflect comparisons of production car MPG's with Certification car MPG's interpolated[54] to exactly the same odometer readings, model-by-model, as the audit data cars (i.e., the most accurate method of comparison). For all 727 cars, a 2% production overage in MPG is indicated; the domestic makes show a 3% overage, and the import cars show a 7% hardware shortfall.

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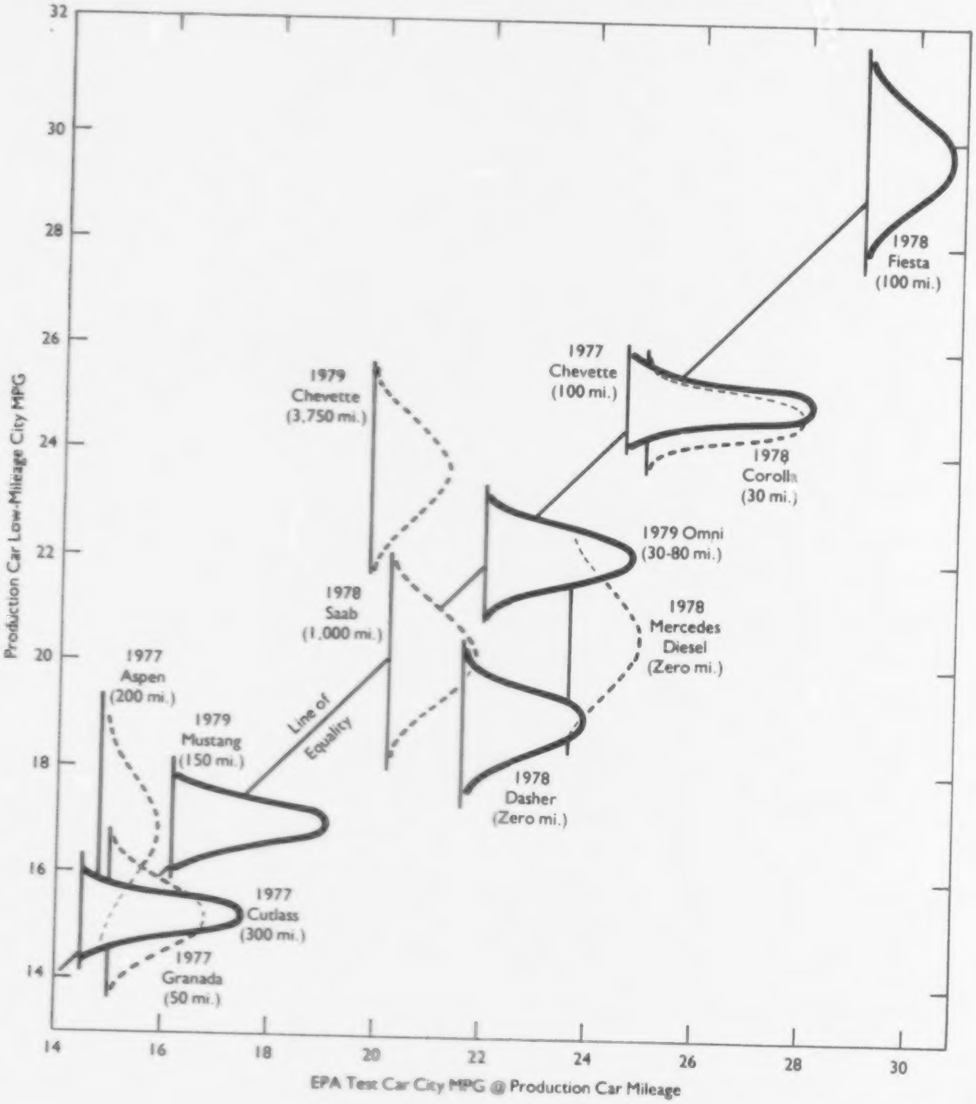
[54] Using each model's zero-mile and 4000-mile Certification MPG values.

Summary of EPA Audit Data, by Manufacturer

Manufacturer	Year(s)	Number Models	Number Cars	Production Hardware Slip (Sample-Wtd)
AMC	1977	1	27	1.121
Chrysler	77-78-79	13	147	1.018
Ford	77-78-79	17	167	1.044
GM	77-78-79	33	316	1.021
Domestic Subtotal		64	657	1.030
Fiat	1979	1	6	0.929
Honda	1979	1	8	0.905
Mercedes-Benz	1978	1	9	0.868
Porsche	1979	1	7	1.047
Renault	1978	1	6	0.863
Saab	1978	1	9	1.031
Subaru	1979	1	6	0.890
Toyota	1978	1	8	0.979
Volkswagen	1978	1	11	0.871
Import Subtotal		9	70	0.931
		Overall Average		1.020

The next figure illustrates the MPG distribution curves for several of the models audited. Those models depicted are the ones with either the maximum or minimum dispersions, or best or worst average slips, for their EPA MPG range; all of the models shown had a test sample size of at least eight. For any EPA MPG level, the widest spreads are approximately ± 2 MPG. On a percentage basis, a maximum spread of ± 2 MPG represents a ± 20% variation for 10 MPG cars, and a ± 7% variation for 30 MPG cars; in terms of fuel consumption, a 20% MPG error at 10 MPG corresponds to an error of 0.02 gallons per mile, while a 7% MPG error at 30 MPG is a consumption error of only 0.002 GPM.

FIGURE 21. New Production Car MPG Distributions



Since Selective Enforcement Audit testing is a continuing effort, additional data which has been acquired since the publication cutoff date has not been evaluated. However, we have no reason to believe that the S.E.A. data reported here is not typical of the now-larger data base.

All of the above apply to hardware variance with respect to EPA City MPG; Highway tests were run by only two of the data sources, Union Oil (1975) and Mobil Oil (1977). Hardware variances for the Highway cycle can be derived from these two sources, but only as an estimate, since zero-mile highway MPG data were not available for the certification cars. These estimated Highway slips are shown below, and are reasonably in line with the values presented earlier for the City MPG values.

Production Hardware Slip, EPA Highway Test

	49 States	California	All
Union Oil (1975)			
Domestic	.956	.959	.957
Import	.973	.908	.965
All	.959	.950	.958
Mobil Oil (1977)			
Domestic	.993		
Import	.990		
All	.992		

5. Vehicle Condition (Test)

This section examines those fuel economy influences for which available data is limited to MPG effects measured in dynamometer tests.

a. Engine Tune - the effects of engines' "state of tune" on fuel economy have been widely investigated, the consensus being that engines out of adjustment with respect to manufacturer specifications suffer fuel economy penalties. Studies[55] of EPA emissions surveillance data on pre-1974 models have shown an average improvement of 6% in MPG for tuned cars, compared to their "as-received" condition. For later model cars the overall effect of maintenance can be estimated by comparing in-use to EPA vehicle slip factors from initial (as-received) tests and tests after maintenance, from the EPA Restorative Maintenance data[56,57]. The resulting MPG changes are:

Fuel Economy Change Resulting
from Vehicle Tuneup

	City	Highway
300 1975-76 models	+1.9%	+0.5%
81 1977 models	+0.1%	-0.8%

The aggregate maintenance effect on MPG for all of these RM cars was a net improvement of 1.5% City and 0.2% Highway. Since some of the cars required no maintenance, all of this average improvement came from those which did, hence that fraction of the cars which actually received maintenance had higher percentage improvements.

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[55] Austin and Hellman, "Passenger Car Fuel Economy - Trends and Influencing Factors", SAE paper 730790, September 1973.

[56] Bernard and Pratt, Op. Cit. (45)

[57] White, Op. Cit. (46).

MPG effects of specific malfunctions as reported by Panzer[58] by White, and by Toulmin[59] are listed in the next table, and indicate that carburetion and spark system problems have the most significant MPG impacts.

Percent Effect on Fuel Economy
of Indicated Malfunction

	Panzer[58] (1975's)		White[57] (75-77's)		Toulmin[59] (77-80's)	
Malfunction	City	Highway	City	Highway	City	Highway
One spark plug misfiring	-13	-15	X	X	X	X
Air/Fuel ratio too rich	-11	-12	X	X	X	X
Ignition timing retarded	-6 (8°)	-4	X	X	X	X
Idle A/F rich	-7	*	-2	+1	-1	+1
Plugged PCV	-4	-3	X	X	X	X
Choke rich	-3	*	-2	-1	*	+1
Idle RPM high	-3	*	X	X	-4	-2
Distributor vacuum low	-1	*	*	-1	X	X
Idle A/F lean	*	*	X	X	X	X
Ignition timing advanced	* (8°)	*	+2 (5°)	+1	+2 (5°)	+1
EGR disabled	X	X	+1	+1	+4	+4
Air Pump disabled	X	X	+1	+1	X	X
Choke heater disconnected	X	X	*	+2	X	X
Idle RPM low	+3	*	X	X	X	X

* = insignificant effect (<0.5%)
X = not evaluated

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[58] Panzer, "Fuel Economy Improvements Through Emissions Inspection/Maintenance", SAE paper 760003, 1976.

[59] Toulmin, "Light Duty Vehicle Driveability Investigation", EPA Report EPA-460/3-78-012, December 1978.

The frequency of occurrence of malfunctions, by engine system, is given in the next table. In terms of emissions performance, those vehicles failing emissions tests show generally higher incidences of engine malfunctions.

Percent of Vehicles with Indicated Malfunction
(1975-1976 Models, EPA RM Program)

	Passing Vehicles	Failing Vehicles	All Vehicles	Most Frequent Item[a]
Air Induction system	6.4	6.3	6.33	Air cleaner element
Carburetor/Fuel System	40.8	84.0	66.00	Idle mixture caps
Ignition System	12.0	36.0	26.33	Timing out of spec.
Exhaust Gas Recirculation	4.0	23.4	15.33	Time delay solenoid
Air Pump	0	1.1	0.67	Disabled
PCV System	0.6	0.8	0.67	PCV Filter
Evap. System	0	2.3	1.33	[b]
Miscellaneous	0	1.7	1.00	Early fuel evap.
At least one malfunction	50.4	91.4	74.33	

[a] based on one test site, not all sites

[b] several items equally frequent

If tuneups are performed on all of a group of cars, whether necessary or not, mixed results can occur. In a study conducted by EPA[60], three vehicles which had been worked on by private garage mechanics and then tuned to specification by EPA technicians showed the following changes in cold-start EPA City fuel economy:

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[60] Plungis, "A Study of Fuel Economy Changes resulting from Tampering with Emission Controls", Report 74-21, Test and Evaluation Branch, ECTD, EPA, January 1974.

Measured MPG (1972 City Test Procedure):

	As Received	Tuned to Spec by EPA	Adjusted by Garage
1973 Compact	17.3	19.3	18.4
1973 Large Wagon	7.7	9.1	9.0
1974 Midsize (3 mos. old)	10.5	10.3	10.2

The two older cars benefited from the maintenance (by 11.5% EPA, 6.4% Garage; and 18.2% EPA, 9.3% Garage, respectively), but the newer car's fuel economy was reduced (1.9% EPA, 2.9% Garage).

In a tuneup study done for DOT, Claffey[61] also reports mixed results for a group of 22 1970-74 model cars, all of which were given plugs/points/condenser replacements, plus other work deemed necessary on an individual basis. The directional changes in MPG are shown in the next table. Quantitative (percentage) changes were not readily discernible from the data. Note that the three cars which had never been tuned up did not always improve in MPG by being tuned.

Mixed Results of Tuneups Given Whether or Not Needed

Effect of Tuneup on MPG: Stop-and-go	Steady Cruise	Number of Cars and Odometer Values* 10 Urban Cars	12 Rural Cars
MPG Better	MPG Better	---	1(12k/7k)
MPG Better	No Change	2(27k/17k)	1(29k/7k)
(No Data)	MPG Better	2(34k/8k)	1(98k/25k)
(No Data)	No Change	1(60k/10k)	---
No Change	No Change	4(25k/17k)	7(39k/12k)
MPG Worse	MPG Better	1(17k/17k)	---
MPG Worse	No Change	---	1(6k/6k)
MPG Worse	MPG Worse	---	1(23k/23k)

*X(Y/Z) = No. Cars (Avg. odometer/Miles since last tuneup)

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[61] Claffey, "Passenger Car Fuel Conservation", DOT Report FHWA-PL-77009, January 1977.

Tuneups may not, in general, have the same effect on all engines. From the EPA 1975-1976 RM data, tuneup effects estimates (derived from before-and-after vehicle slip factors) seem to vary with engine size, as follows:

Engine Displacement: (Cubic Inches)	Change in Relative MPG: City	Highway
≤225	-0.7%	-0.3%
226-229	+0.6%	+1.2%
300-360	+2.4%	+0.4%
>360	+3.5%	+0.9%

It is not clear whether the smaller engines did not improve in MPG because they responded poorly to maintenance or because they were in less need of maintenance.

A Canadian Survey[50] shows that smaller engines are tuned up more frequently than larger ones:

Fraction of Cars Receiving Tuneups:

Mileage Interval Between Tuneups	4-cylinder Models	6-cylinder Models	8-cylinder Models
0 - 3000	19%	18%	10%
3001 - 6000	48%	45%	36%
6001 - 12,000	30%	31%	44%
12,000	3%	6%	10%
Approximate Average	5600	6000	7200

The apparent engine size dependency in the RM data could be influenced by similar "miles-since-last-tuneup" factors.

Many of the foregoing findings emphasize the need for a determination (through careful inspection) of whether engines in fact need to be tuned up. By making this kind of determination, the inspection and maintenance (I/M) programs currently being developed by EPA and the States will maximize the fuel economy benefits of proper engine maintenance.

In an EPA report[62] the available data on the fuel economy impact of I/M programs was evaluated in some detail. One basic conclusion was that the fuel economy benefit of an I/M program depends to a great extent on the capability of the mechanics who perform the tuneups. Without emission-oriented mechanic training, the fleetwide fuel economy benefit is estimated to be negligible; but with emission-oriented mechanic training, we can expect fleetwide benefits of about 1 per cent for current types of cars and possibly more for 1981 and later models.

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[62] "Effects of Inspection and Maintenance Programs on Fuel Economy", Report IMS-001/FE-1, Inspection and Maintenance Staff, ECTD, EPA, March 1979.

b. Engine Response to Fuel Properties - One special class of vehicle condition effects requires separate mention: that of relationships between fuel properties and engine operation, specifically with regard to fuel economy. Of many fuel properties which have been investigated by EPA[63,64], four have the potential for affecting fuel economy to any measureable extent:

- Fuel density
- Octane rating
- Volatility
- Additives

Fuel density has a straightforward fuel economy influence, in that the denser the fuel, the higher the heat content per gallon consumed; in general this means more available work per gallon, and hence more miles per gallon for a constant amount of work per mile. The SAE test procedures' correction factors[65] reflect MPG effects as follows:

$$\frac{MPG(SG)}{MPG(.737)} = \frac{1}{1 + 0.8(0.737-SG)}$$

where MPG(SG) = MPG with fuel of specific gravity = SG (dimensionless);
MPG(.737)= Reference MPG, with fuel of specific gravity = 0.737

$$\text{or:}\quad \frac{MPG(API)}{MPG(60.5)} = \frac{1}{1 + 0.0032(API-60.5)}$$

where MPG(API) = MPG with fuel of gravity[66] = API(degrees);
MPG(60.5) = Reference MPG, with fuel of API gravity = 60.5°

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[63] Bascunana and Stahman, "Impact of Gasoline Characteristics on Fuel Economy and Its Measurement", Report 76-10, Technology Assessment and Evaluation Branch, ECTD, EPA, December 1976.

[64] Harvey, "Representativeness of Emissions Certification Gasoline", Draft Report, Technology Assessment and Evaluation Branch, ECTD, EPA, July 1978.

[65] Society of Automotive Engineers, "Fuel Economy Measurement--Road Test Procedure--J1082b", January 1979.

[66] API gravity and specific gravity are related by: $API^{o} = \frac{141.5}{SG} - 131.5$

Reference 63 reports a relationship involving fuel density directly:

$$\frac{MPG(\rho)}{MPG(\rho_o)} = \frac{47,400 + 10,960\rho}{47,400 + 10,960\rho_o}$$

where MPG(ρ) = MPG with fuel of density[67] = ρ(lb/gallon);
MPG(ρ_oo) = Reference MPG, with fuel of density = ρ_o

This relation is about the same as the SAE J1082 factors, and indicates that fuel economy changes by about 10% for each lb/gal change in fuel density.

Average density[68] of EPA unleaded test fuel in 1977-78 was 6.16 lb/gallon[69] from numerous EPA measurements, to 6.17 lb/gallon for EPA fuel analyzed by DOE's Bartlesville Energy Technology Center. By comparison, densities of commerical fuels, as reported by the Motor Vehicle Manufacturers Association and DOE for recent years, are:

In-Use Fuel Gravity and Density
Degrees API:

	MVMA	DOE	Average lb/gallon
Unleaded, summer, 1976	59.2	59.7	6.18
1977	58.5	59.3	6.20
1978	58.9	58.8	6.20
Unleaded, winter,			
1975-76	--	61.8	6.11
1978-79	--	60.3	6.16

The slightly higher summer grade densities would tend to give road MPG overages from 0.2% to 0.4%, while the winter grade densities would correspond to road shortfalls from zero to 0.5%. Hence, no significant net fuel economy effect can be associated with differences between average densities of EPA unleaded fuel and in-use unleaded fuels.

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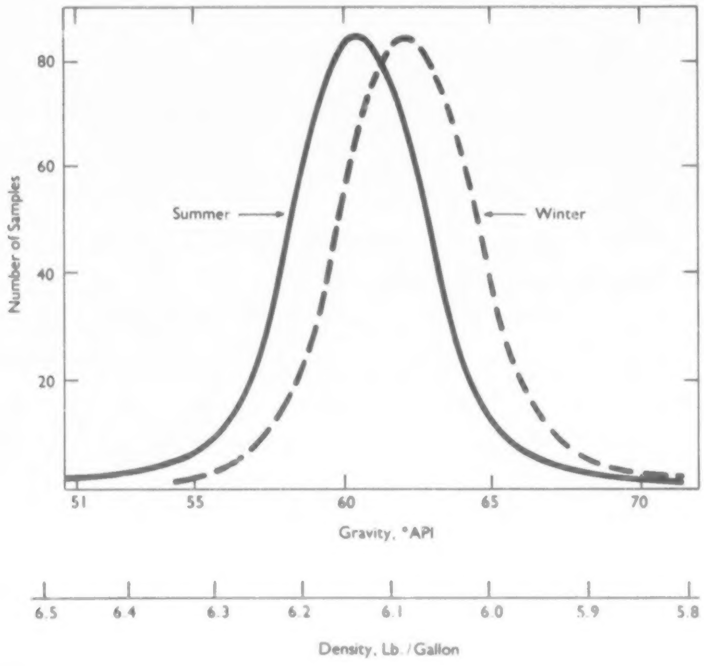
[67] Fuel density and specific gravity are related by: $\rho = SG \times 8.3$.

[68] Harvey, Op. Cit. and Johnson, "Composition and Octane number of U.S. Motor Gasolines Sampled in the DuPont 1978-79 Winter Road Octane Survey", DOE Report BETC-0012-1, September 1979.

[69] Average API gravity = 60.2°

There is some variation in in-use fuel density which can cause road MPG differences for individual drivers, or all drivers in certain locales. The figure below illustrates the distributions of API gravities and densities for gasolines from a 1972 nationwide sampling[70]. The extremes of these distributions correspond to fuel economy variances of ± 3%.

FIGURE 22. Distribution of API Gravity, 1972



The DOE surveys mentioned above reveal density differences from one region of the country to another: while the U.S. average API gravity for 1978-79 winter unleaded gasoline was 60.3, regional extremes and their respective road MPG differences were:

	°API	lb/gallon	MPG Effect vs. EPA Fuel
Seattle	56.4	6.28	+1.2%
Wichita/Oklahoma City/Tulsa	64.3	6.03	-1.2%

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[70] Phillips Petroleum Co., unpublished.

Fuel Octane Rating itself has no direct effect on fuel economy[63,64], that is, supplying higher or lower octane fuel to an engine will not result in an MPG change as long as the engine runs acceptably on either fuel[71]. Parameters closely related to fuel octane which do affect fuel economy, and emissions, are compression ratio and spark timing. Fuel economy tends to increase with increased compression ratio and increased spark advance; unfortunately, so does engine knock tendency. To keep engine knock at acceptable levels while increasing compression ratio and/or spark advance, fuel octane must be increased or the "mechanical octane" of the engine must be increased. To control both engine knock and emissions, the compression ratio, spark advance, fuel octane requirements, and other engine design factors must all be optimized.

Up to model year 1974, auto manufacturers included compression ratio reductions and spark retard in their approaches to emission control, and octane requirements accordingly were eased for these vehicles[72]. For post-1974 models, improved emission control technology has allowed optimization for more fuel-efficient compression ratios and spark advance calibrations. Most recently, turbocharging has been introduced to take fuel economy advantage of reduced engine displacements.

All of these developments have tended to cause late model vehicles' octane appetites to increase. These vehicle octane requirements are typically reported via a graphical "percent satisfaction" relationship, an example of which appears in the next figure[73].

The term "percent satisfied" that appears on the figure needs to be explained. The tests used to generate these types of graphs are conducted

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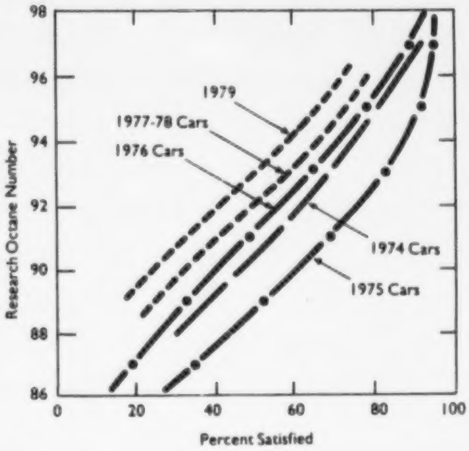
[71] Cars equipped with knock sensor systems are an exception, as will be discussed later.

[72] Octanes of commercial fuels were not correspondingly reduced, however; instead, average octane remained relatively constant while customer satisfaction improved. See: Courtney and Newhall, "A Primer on Current Automotive Fuels", Automotive Engineering, December 1979.

[73] Ethyl Corporation, "Automotive Developments '79--A Survey for the Oil Industry", 1979.

FIGURE 23. New-Car Fuel Octane Requirement



by trained technicians who are more sensitive to knock than is the motoring public. Reference 72 states:

> "'Trace Knock' is the knock intensity detectable by a trained technician. Octane requirement measured by a trained rater is about five or six RON's above the average an average untrained observer would determine."

A factor which tends to offset this, however, is Octane Requirement Increase (ORI). It is well-documented[74-78] that the octane requirement of an automotive engine increases during service. Reference 64 reports that octane requirements increase 5 to 12 numbers (RON) in 10,000 to 30,000 miles, after which they remain constant.

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[74] Coordinating Research Council(CRC), "Influence of Leaded and Unleaded Fuels on ORI in 1971 Model Cars, Phase I: 1970-71 CRC Road Rating Program", Report No. 451, September 1972.

[75] CRC, "Octane Requirement Increase in 1973 Model Cars, Phase II: 1973 CRC Road Rating Program", Report No. 476, February 1975.

[76] Niles and McConnell, "Establishment of ORI Characteristics as a Function of Selected Fuels and Engine Families", SAE Paper 750451, 1975.

[77] Ahlquist, et al, "Some Observations of Factors Affecting ORI", SAE Paper 750932, 1975.

[78] Benson, "Some Factors which Affect Octane Requirement Increase", SAE Paper 70933, 1975.

The octane levels for fuel of recent years are shown in the next table.

Octane Ratings of In-Use
Unleaded Gasoline

	Research Octane (RON)			Motor Octane (MON)	
	MVMA	DOE	Chevron[72]	MVMA	DOE
Summer 1975	--	92.1	92.0	--	--
1976	92.1	92.4	92.2	84.1	84.1
1977	93.1	92.5	92.7	83.4	83.8
1978	92.4	93.0	92.8	83.1	83.9
Winter 1975-76	--	92.3	--	--	--
1978-79	--	92.5	--	--	83.8

In the worst case, it could be assumed that all of the in-use spark maladjustment that was observed in the EPA Restorative Maintenance (RM) data relates to dissatisfaction (at the levels in the figure above) with the octane of the fuel. The resulting computation implies a fleetwide fuel economy shortfall of 0.6% for this factor. While not an absolute upper bound, we feel that this is a conservative estimate, i.e., greater than the actual value that would be calculated if all of the necessary data and all of the reasons for in-use spark maladjustment were known precisely.

Knock Sensors - Some vehicles are being introduced equipped with knock sensor systems. In general, these systems incorporate a sensor which detects engine knock and, based on the signal that indicates that incipient knock is present, adjusts the spark timing to eliminate the knock.

Whether or not a shortfall in MPG occurs with knock sensor equipped vehicles depends on several factors. First, the details of the control logic must be known. Systems could be designed to always operate at or just below the knock threshold, but others could be designed just to retard from a fixed (vacuum/mechanical or electronic) timing calibration. Secondly, the fuel octane that the base calibrations were determined for must be known. Calibrations could be tailored for EPA's high octane test fuel or they could be tailored for typical in-use fuel properties. Thirdly, the octane of the fuel that was actually used for the official EPA test should be known. Although the vast majority of the tests are run on high octane EPA test fuel, some vehicles with knock sensors have been tested on lower octane fuel in response to a manufacturer request for special test procedure. Fourth, the actual in-use spark timing history of the vehicle, compared to the spark timing that occurred on the EPA test should be known to allow the overall effect to be evaluated. For example: a vehicle might have a system that results in a negative vehicle slip when evaluated on a dynamometer with in-use fuel, but might also have a positive road slip (due to more advance under many different operating conditions) that could cancel or offset the vehicle slip.

The above discussion should not be taken to indicate that knock sensor equipped vehicles are not and will not be a source of shortfall. As long as EPA continues to use high octane fuel for testing, the potential for a knock sensor shortfall will exist. EPA is investigating the whole issue of the representativeness of its current test fuels, looking at octane as well as other fuel properties. It is interesting to note, however, that even if EPA did use a low octane fuel for testing, any shortfall due to overly aggressive spark timing calibrations may not be entirely eliminated, because the presence or absence of any degree of knock during a test is not now a criterion that determines the acceptability of an emission or fuel economy test.

Fuel Volatility is an important property due to its influence on such performance parameters as vapor lock, driveability, startability, carburetor icing, and oil dilution.

Some volatility characteristics of in-use and EPA unleaded summer gasolines are compared in the next table:[64]

Distillation Temperature, °F (ASTM D86)

	1976		1977		1978		1977-78 EPA	
	MVMA	DOE	MVMA	DOE	MVMA	DOE	Avg.	Range
IBP	93	89	88	89	87	89	88	82-92
10%	126	121	125	121	123	120	126	121-134
50%	221	220	221	221	220	220	221	217-228
90%	336	332	331	333	336	333	310	304-318
EP	414	411	414	410	413	409	399	389-406

The initial boiling point (IBP) and 10% and 50% evaporation points for EPA fuel are about the same as for the 1976-78 commercial fuels, but the 90% point and end point (EP) indicate higher volatility for EPA fuel. Since this upper end of the fuel distillation curve is believed to be important for driveability of vehicles with today's quick-release chokes, such vehicles could tend to be vulnerable to problems with overly lean air/fuel ratios when operating on less volatile fuels. The in-use "fix" for such problems is usually enrichment of the idle mixture or choke setting. Again referring to Section IV.B.5.a., fuel economy effects of idle and choke enrichments have been reported to be:

	EPA City Test	EPA Highway Test
Rich idle mixture	-1% to -7%	zero to +1%
Rich choke	zero to -3%	-1% to +1%

The average EPA 55/45 MPG penalty for these effects, if they always occur in combination and if they interact linearly (the worst case assumptions), is 2.4%. As was done for octane considerations above, it could be inferred that those vehicles found in the 1975-76 RM program with carburetor or air induction system maladjustments (72% of all vehicles) were in that condition due to EPA/in-use fuel volatility differences and were incurring said 2.4% penalty in-use. Making these worst-case assumptions, the maximum fleet MPG penalty due to the volatility gap between EPA fuel and in-use fuels would be 1.7%.

Additives - In-use fuels use a wide variety of additives, most of which are present in such small quantities that fuel economy is not affected. When additives are present in significant amounts, however, miles per gallon of the blended fuel can vary if the heating value of the additive(s) is significantly different from that of gasoline. For example, early results from our own studies on 10% alcohol blends ("gasohol") have shown volumetric MPG penalties on the order of 3%. Naturally, gasoline consumption is reduced by about 7% with this blend, but individual motorists using gasohol can expect to pump slightly more total fuel.

6. Summary Findings: Vehicle Slip

The overall average shortfalls attributable to vehicle slip items are summarized below:

Effects of Vehicle Slip Influences
on Fuel Economy

Influence	Relative MPG	Fleet MPG Shortfall
Production Slip:		
Administrative Variance	0.999	-0.1%
Hardware Variance	0.985	-1.5%
Vehicle Condition (Test)		
Engine Tune	0.990	-1.0%
Engine/Fuel Response	0.977	-2.3%
Brake Drag	0.998	-0.2%
Wheel Alignment	0.999	-0.1%

If all of these factors act independently, a total shortfall of about 5% can be associated with Vehicle Slip. Recalling that the three-year average Vehicle Slip shortfall from DOE-furnished data (Section IV.A) is 4.7%, the influences included in our Vehicle Slip category--and our estimates of their respective magnitudes--must be concluded to be reasonably accurate.

Note that influences of brake drag and wheel misalignment are included. These items are discussed later under Road Slip, but part of their effect--that associated with the two vehicle wheels which drive the dynamometer rolls--is indeed measured in dynamometer tests. Hence, a proper accounting of effects which show up on the dynamometer must include these factors.

The two subcategories under Production Slip have been found to have different MPG influences as a function of model year, as follows:

Model Year Trends, Production Slip Items
(Average Percent Deviation from EPA Label/Guide MPG)

	Model Year: 1974	1975	1976	1977	1978	1979
Administrative Variance	--	+1.3%	-1.1%	-1.6%	+0.9%	--
Hardware Variance	+0.6%	-7.5%	-8.0%	+3.3%	+1.4%	+1.2%

The significant hardware shortfalls in model years 1975 and 1976 are believed related to the instantaneous injection of innovative emission control technology into the fleet in those model years. Since these shortfalls have not reappeared in 1977-78-79--although much of that technology is still in use--we regard the 1975-76 slips as a temporary response to the rapidity with which that technology was introduced, rather than to shortcomings inherent in the techology itself.

As discussed in Section B.3, there seems to be a pattern of higher Vehicle Slip shortfall for higher-MPG cars after break-in. This "MPG tilt" does not appear to be characteristic of very low-mileage cars. Since vehicle-condition influences take hold with increased vehicle odometer mileage accumulation, the appearance and growth of MPG tilt must be due to vehicle condition. This area definitely warrants further study.

FUEL ECONOMY INFLUENCES (Cont'd.)

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C. Road Slip

The preceding discussion of vehicle slip considered only the fuel economy behavior of production cars when operated according to the specific procedures and conditions of the EPA tests. In this section, we will consider the wider range of conditions to which vehicles are exposed in actual use, and observed or estimated fuel economy sensitivity to these conditions. We have grouped these factors under four basic headings:

- The Travel Environment - Conditions in which travel occurs, such as weather and road surface, over which a driver has minimal control--other than basic route selection, or simply the decision not to travel at all;

- Travel Characteristics - Details of the travel itself, such as average speed, stopping frequency, and trip length, over which a driver has partial control but is constrained by traffic flow and the peculiarities of the trip route (speed limits, intersections, lights, etc.): driving technique is also an important travel characteristic, over which a driver has virtually total control;

- Vehicle Condition (Road) - The "state" of the vehicle as configured for traveling, including its mechanical condition and load; most of these factors are matters of choice; and

- Simulation Variance - Specifics of the EPA test which could lead to either random variation, or directional offsets from real-world fuel economy; and details related to mileage measurement, fuel measurement, and miles-per-gallon calculation.

From earlier sections of this report, average in-use MPG shortfalls were shown to have a definite dependence upon EPA MPG level for most of the model years studied. In assessing fuel economy sensitivity to the in-use factors, we have considered vehicle vintage and engine/ emission control technology effects as they might relate to model year differences, and have evaluated vehicle size effects as possible explainors of tilts in shortfall with EPA MPG level.

It must be emphasized that most of the fuel economy sensitivity measurements reported here were derived from classical, "good engineering practice" methods of testing, namely, measurement of the fuel economy effect of one single variable at a time while going to great lengths to hold all other influences constant. Unfortunately, when attempting to assess the combined impact of a number of separate factors, their inter-dependence is not fully known, and the resulting combined fuel economy effect is somewhat of an estimate. Given an individual car with a known in-use MPG capability under conditions which do match those of the EPA tests, no one really knows precisely what fuel economy it will get when driven aggressively around a snow-covered gravel curve on a 3% grade in 22°F weather, with an out-of-tune engine, misaligned wheels, and underinflated tires, towing a trailer. Most would agree it would not be very good, but the precise factor that should be applied to account for these combined influences is not immediately apparent, even if each individual MPG effect were known for that type of car.

1. The Travel Environment

Included in this category are three weather conditions: ambient temperature, barometric pressure (altitude), and wind (aerodynamics); and three road characteristics: gradient, surface type and condition, and curvature.

a. Ambient Temperature: The table lists temperature sensitivities for a number of operating conditions, including steady cruises and cyclic driving. For "cold-start" cycles, the MPG effect shown does not include the effect of warmup, but only the sensitivity of MPG to ambient temperature after some 15 miles of driving (7.5 miles and 10.2 miles, respectively, in the case of the EPA City and Highway cycles).

While a temperature sensitivity of 1.0% to 1.5% per 10°F is generally accepted, it is clear from these data that that sensitivity is characteristic of pre-1975 cars, basically large ones using relatively unsophisticated emission control technology and calibrations. There is abundant evidence that later-model conventional cars are more temperature-sensitive than pre-1975's and also that smaller cars suffer higher percentage losses than do larger ones. To

Effect of Temperature on Fuel Economy
(Percent MPG Change per 10°F Temperature Change)

A. Steady Cruise, Warmed-up

	20 mph	30 mph	40 mph	50 mph	60 mph	70 mph
Claffey[79]	2.3	2.0	1.9	1.8	1.6	1.5
Chrysler[80]	2.5	2.2	1.9	1.5	1.2	0.9

B. Manufacturer and SAE Cycles, Warmed-up

Scheffler/Niepoth[81] and
Tobin/Horowitz[82]. 1.1
(GM Urban)

Chrysler[80]. 2.6
(Chrysler ColdStart Urban)

AMC[83] 1.1-1.6
(SAE Suburban)

SAE[84] 1.4
(SAE Urban, SAE Suburban,
SAE Interstate)

EPA Analysis of Mobil Oil[85] Data:
(SAE Urban)
2000 lb, 3.1
3000 lb, 2.4
4000 lb, 1.6
5000 lb, 0.9

C. EPA City Cycle, Warmed-up

Eccleston, et al[86] . .Pre-1975, 0.7
1975 Models, 1.2
1973 Diesel, 2.0
PROCO Prototype, 1.3

EPA Dyno/Track[87] . . . . City, 2.0
Highway, 2.1

Eccleston/Hurn[88] . . . City, 1.4
Highway, 0.5

Gulf Oil[89] 2.0

EPA Chicago[90] 0.7

Marshall[91] Gasoline Cars . . 2.0
Diesel Cars . . 0.3

D. EPA City Cycle, after Cold Start

Eccleston, et al[86] . Pre-1975, 1.8
1975 Models, 2.0
1973 Diesel, 2.4
PROCO Prototype, 1.6

EPA CO Hot Spot[92] NYC Cycle, 3.9
EPA FTP, 0.8

EPA Chicago[90] 1.7

Ostrouchov[93] . . . . 2000 lb, 6.4
3000 lb, 4.5
4000 lb, 2.6
5000 lb, 2.4

Eccleston/Hurn. 2.7

Hayden[94] 1976-8 Conventional, 4.3
1976-8 Lean Burn, 2.7
1978 Stratified Chg, 2.7
1978 Diesel, 2.4
1978 Turbocharged, 1.7

Ostrouchov[95]

2000 - 2500 lb	1975 Conventional,	6.0
	1978 Lean Burn,	1.8
	1978 Diesel,	1.8
3000 - 3500 lb	1975 Conventional,	3.4
	1978 3-Way Catalyst	2.3
4500 - 5000 lb	1975 Conventional,	2.7
	1978 Diesel,	1.3

E. EPA Combined Cycles, City Cold/Hot, Highway Warmed-up

Hayden[94]	1976-8 Conventional,	3.2
	1976-8 Lean Burn,	2.0
	1978 Diesel,	2.0
	1978 Turbocharged,	1.3

F. In-Use Driving

EPA Analysis of GM[96] Data. 1.2

---

[79] Claffey, "Running Costs of Motor Vehicles as Affected by Road Design and Traffic", NCHRP Report 111, 1971.

[80] Chrysler Corp. data, submitted to: SAE Passenger Car and Light Truck Fuel Economy Measurement Committee (unpublished).

[81] Scheffler and Niepoth, "Customer Fuel Economy Estimated from Engineering Tests, SAE paper 650861, November 1965.

[82] Tobin and Horowitz, "The Influence of Urban Trip Characteristics on Vehicle Warm-up -- Implication for Urban Automotive Fuel Consumption", SAE paper 790656, June 1979.

[83] American Motors data, submitted to: SAE Passenger Car and Light Truck Fuel Economy Measurement Committee (unpublished).

[84] Society of Automotive Engineers, Op. Cit. (65).

[85] Mobil Oil Co. data, submitted to: SAE Passenger Car and Light Truck Fuel Economy Measurement Committee (unpublished).

[86] Eccleston et al, "Ambient Temperature and Vehicle Emissions", EPA Report 460/3-74-028, October 1974.

[87] Data from EPA Dyno/Track Project, Phase II (unpublished).

[88] Eccleston and Hurn, "Ambient Temperature and Trip Length -- Influence on Automotive Fuel Economy and Emissions", SAE paper 780613, June 1978.

[89] Gulf Research and Development Company, "Passenger Car Fuel Economy in Short Trip Operations", DOE Report HCP/W4248, July 1978.

[90] "Effects of Low Ambient Temperature on the Exhaust Emissions and Fuel Economy of 84 Automobiles in Chicago", Report 78-3, Technology Assessment Evaluation Branch, ECTD, EPA, October 1978.

amplify on the latter effect, a 2.5% penalty on a 15-MPG large car yields a loss of 0.4 MPG, but a 5.0% penalty on a 30-MPG small car results in a loss of 1.5 MPG.

The data of the Canadian researchers (Hayden, and Ostrouchov) indicate that vehicles powered by engines representative of future technologies appear to be about one-half as sensitive to temperature as late-model conventionally-powered cars.

These findings have bearing on the larger in-use shortfalls observed for post-1974 models, and also may become important in the future, as vehicle sizes shrink and new technology usage becomes more widespread.

The next table shows an estimate of the cumulative nationwide effect of temperature on fuel economy. Using distributions of vehicle-miles traveled as a function of temperature, and fuel economy responses of both "small" and "large" cars to these temperatures, we can account for in-use MPG shortfalls of 4 to 8% relative to the EPA test temperatures.

It will be noted that this computation assumes a continued rise in fuel economy at temperatures up past 100°F, which is appropriate only for non-air conditioned vehicles. The fuel economy penalties due to air conditioner operation will be discussed later.

---

[91] Marshall, "Potential for Improving Short-Trip Fuel Economy by Fuel Formulation", SAE paper 790655, June 1979.

[92] Service and Kranig, "CO Hot Spot Preliminary Investigation", Report 77-13, Technology Assessment and Evaluation Branch, ECTD EPA, December 1977.

[93] Ostrouchov, "Effect of Cold Weather on Motor Vehicle Emissions and Fuel Economy", SAE paper 780084, February 1978.

[94] Hayden, "The Effects of Technology on Automobile Fuel Economy under Canadian Conditions", SAE paper 780935, November 1978.

[95] Ostrouchov, "Effect of Cold Weather on Motor Vehicle Emissions and Fuel Consumption -- II", SAE paper 790229, February 1979.

[96] General Motors 1975 Customer Survey (unpublished)

Temperature Distribution and Estimated MPG Effect

Temperature, °F	% of VMT[a]	MPG Relative to EPA MPG[b] Small Cars	MPG Relative to EPA MPG[b] Large Cars
<10	0.5	.692	.854
10-20	2.0	.752	.882
20-30	6.4	.792	.901
30-40	12.2	.832	.920
40-50	14.6	.872	.939
50-60	16.1	.912	.958
60-70	18.3	.952	.977
70-80	18.6	.992	.996
80-90	9.2	1.032	1.015
90-100	1.8	1.072	1.034
>100	0.3	1.120	1.058
VMT-Weighted Average:	57°F	.920 (Shortfall =8.0%)	.961 (Shortfall =3.9%)

---

[a] from Ref. 97; EPA test temperature = 68-86°F;

66% of VMT below EPA temperature
28% in EPA range
6% above EPA temperature

[b] Reference temp = 77°F (EPA MPG = 1.00)

Small-car Sensitivity = +4.0% per 10°F
Large-car Sensitivity = +1.9% per 10°F

---

[97] U.S. Department of Transportation, "The Sensitivity of Projected Aggregate Fuel Consumption to the Conditions of Individual Fuel Economy Tests--Part A", Draft, May 1974.

b. Barometric Pressure/Altitude: This effect is not without some controversy. The most frequently quoted reference on altitude effects, Ref. 79, indicates a large MPG penalty for operation at high altitude. The reference also states (but this is rarely mentioned) that the penalty applies to uphill driving on a 10% grade. The same reference also states that for level road operation there is no MPG effect at least up to 2000 feet.

In its correction factors, the SAE fuel economy road test procedure[65] specifies a reduction of low-pressure (high altitude) fuel economy test data to correct it to standard conditions, reflecting a fuel economy increase caused by the high altitude condition; the magnitude of the correction increases for higher speeds. More recent data, as shown in the next table, do confirm the MPG improvement of high-altitude operation at low speeds, but reveal small losses at higher speeds.

In the most tightly controlled of these projects, Ref. 99, a group of cars was tested at low altitude, then trucked to a high altitude lab. At that point, the vehicles had drifted out of tuneup specifications due to the altitude; tested in this condition, they showed a 1.0% City MPG improvement over the low altitude baseline. Upon being retuned to specification under the high altitude conditions, they saw an additional 2.4% MPG improvement.

As shown in the next table, following, the estimated nationwide effect of altitude on fuel economy is quite small, due to the low fraction of vehicle miles traveled at high altitude, the low absolute magnitudes of the MPG sensitivities, and the offsetting tendency of the positive and negative signs assumed for city and highway sensitivities, respectively.

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[98] Liljedahl and Terry, "A Study of Exhaust Emissions from 1966 through 1976 Denver, Chicago, Houston, and Phoenix", EPA Report EPA-460/3-77-005, August 1977.

[99] Edwards, Liljedahl et al, "1970 Passenger Car High Altitude Emission Baseline", SAE paper 790959, October 1979.

Effect of Altitude/Barometric Pressure on Fuel Economy

A. Steady Cruise, warmed up

		30 mph	40 mph
Claffey[79] (one 1964 car)	2000 ft	No change	0.6% loss
	2500 ft	1.8% loss	1.6% loss
	3000 ft	3.3% loss	4.0% loss
	3500 ft	7.8% loss	9.1% loss
	4000 ft	18.9% loss	21.2% loss

Note: The Claffey data is for a 10% grade;
all other data is for level road conditions.

Liljedahl and Terry[98] (30 models, Denver cars vs. Chicago and Houston cars, 1976 models)	30 mph, 4.0% gain at 5500 ft 60 mph, 1.0% loss at 5500 ft

B. SAE Cycles, warmed up

AMC[83] (Ford Suburban Cycle)	32.0 in. Hg	1.6% loss
	29.8 in. Hg (Detroit)	Base
	28.0 in. Hg	1.9% gain
	26.0 in. Hg	3.0% gain
	24.9 in. Hg (Denver)	3.8% gain
	22.0 in. Hg	5.4% gain
	20.0 in. Hg	6.2% gain

SAE[65]	Urban, no effect Suburban, 0.72% gain per in. Hg decrease 55 mph Interstate, 0.84% gain per in. Hg decrease 70 mph Interstate, 1.44% gain per in. Hg decrease

C. EPA Cycles

Liljedahl and Terry (20 models, Denver cars vs. Phoenix and Chicago cars, 1970 models)	EPA cold/hot City, 3.7% gain at 5500 ft
Edwards, Liljedahl *et al*[99] (25 cars tested at St. Louis, then at Denver, 1970 models)	EPA cold/hot City, 3.4% gain at 5500 ft
Liljedahl and Terry (Denver cars vs. Chicago, Houston, and Phoenix cars, 1976 models)	EPA cold/hot City, 0.9% gain at 5500 ft (31 models); EPA Highway (warmed-up), 0.9% loss at 5500 ft (27 models)

Altitude Distribution and Estimated MPG Effect

Altitude, Feet	% of VMT[a] Urban	% of VMT[a] Rural	MPG Relative to EPA MPG[b] City	MPG Relative to EPA MPG[b] Highway
<500	56	32	0.996	1.001
500-1000	29	26	1.000	1.000
1000-2000	11	23	1.004	0.999
2000-5000	4	16	1.016	0.995
>5000	1	4	1.031	0.990
VMT-Weighted Average:	750'	1300'	0.999	0.999

Combined City-Highway
Factor = 0.999
(shortfall = 0.1%)

---

[a] From Ref. 97; EPA test altitude = 897.5 feet;
56% Urban/32% Rural VMT below EPA altitude
29% Urban/26% Rural VMT ≈ EPA altitude
16% Urban/43% Rural VMT above EPA altitude

[b] Reference altitude = 897.5 feet;
Urban Driving Sensitivity = +0.0006% per ft.
Rural Driving Sensitivity = -0.0002% per ft.

c. Wind and Aerodynamics: Most of the technical literature expresses fuel economy effects in terms of response to a change in aerodynamic drag horsepower, occasioned by a change in effective frontal area, drag coefficient, or both. It will be noted in the next table that aerodynamic losses depend strongly on vehicle speed. The figures below[100] illustrate why: At low cruise speeds, chassis losses[101] are the primary source of energy consumption; at higher speeds, aerodynamic drag becomes the dominant energy loss.

FIGURE 24. Vehicle Road Load Horsepower Versus Vehicle Speed

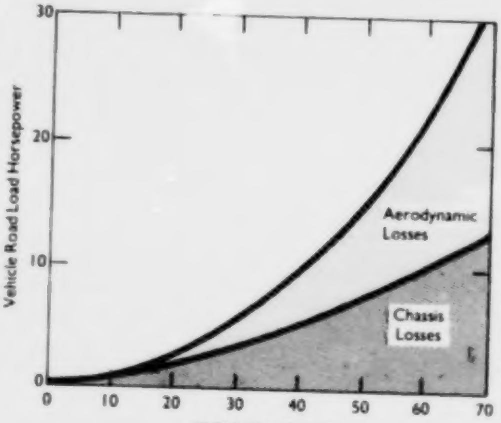
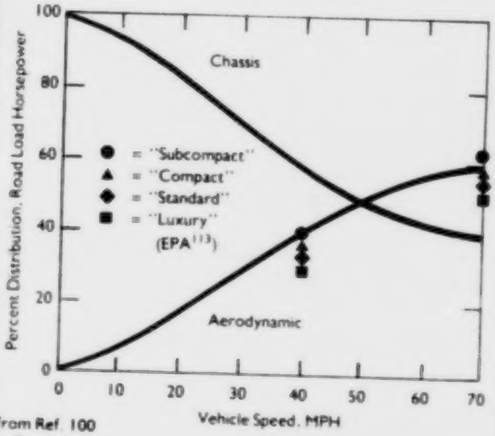


FIGURE 25. Distribution of Road Load Horsepower Versus Vehicle Speed



Curves from Ref. 100
(4 Passenger Compact Car)

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[100] Tenniswood and Graetzel, "Minimum Road Load for Electric Cars", SAE paper 670177, 1967.

[101] Tire rolling resistance and rotational friction losses in the drive train.

Effect of Wind/Aerodynamics on Fuel Economy

A. Steady Cruise

Cornell[102], 18 mph Headwind	70 mph, 16.5% loss
18 mph Crosswind	2.2% loss
18 mph Tailwind	19.4% gain
Huebner/Gasser[103], 10% change in aero drag	70 mph, 4.3%
DOT[104], 10% change in aero drag	50 mph, 3.5% 70 mph, 4.2%
Hurter et al[105], 10% change in aero drag:	at 50 mph: Compact cars, 1.3-1.6% Large cars, 0.8-1.1% at 70 mph: Compact cars, 2.0-3.0% Large cars, 1.7-1.9%
Pierce[106], 10% change in aero drag	20 mph, 0.5-1.1% 30 mph, 0.7-1.4% 40 mph, 1.0-1.7% 50 mph, 1.2-2.7% 60 mph, 1.8-3.0% 70 mph, 2.7-3.8%

B. Cyclic Driving

Huebner/Gasser[103], 10% change in aero drag (Chrysler Urban Cycle)	"Negligible"
Ambs[107], 10% change in aero drag (EPA Urban Cycle)	225 CID engine, 0.9% 318 CID engine, 0.7% 400 CID engine, 0.6%
DOT[104], 10% change in aero drag	EPA City Cycle, 0.6% EPA Highway Cycle, 2.3%
Hurter, et al[105], 10% change in aero drag (EPA City Cycle)	Compact cars, 0.4-0.5% Large cars, 0.3%
Ford[108], 10% change in aero drag (EPA Combined City/Highway)	4-cyl. Cars, 2.2-6.3% 6-cyl. Cars, 2.9-8.1% 8-cyl. Cars, 2.2-5.3%
Nedley[109], 24% change in C_DA (EPA Combined City/Highway)	1980 x-car, 7.2%

Change in Gal./100 Miles:	Per HP Change in 50 mph Road Load	Per Sq. Ft. Change in C_DA	
	Ford	Marks[110] (Compact car)	Marks/Neipoth[111] (Nominal car)
SAE Urban Cycle	-	0.027	0.024
EPA City	-	0.054	0.058
GM Surburban	-	0.049	0.048
EPA 55/45	0.1	-	0.095
EPA Highway	-	0.188	0.140
SAE Interstate	-	0.42	-

Aerodynamic losses also generally depend on vehicle *size*. As pointed out by West *et al*[112], the relationship between frontal area (which, along with drag coefficient, governs aerodynamics) and weight (which governs chassis losses) varies with vehicle size:

Relation between Frontal Area, Weight, and Vehicle Size

	Frontal Area (Sq. Ft.) Per Pound of Vehicle Wt.
1975 Cadillac Sedan	0.0044
1975 Cadillac Seville	0.0047
1975 Honda Civic	0.0074
1975 VW Beetle	0.0089

---

[102] Cornell, "Passenger Car Fuel Economy Characteristics on Modern Superhighways", SAE paper 650862, November 1965.

[103] Huebner and Gasser, "General Factors Affecting Vehicle Fuel Consumption", SAE paper 730518, May 1973.

[104] U.S. Department of Transportation, "Analysis of 1973 Automobiles and Integration of Automobile Components Relevant to Fuel Consumption", Draft, September 1974.

[105] Hurter, *et al*, "A Study of Technological Improvements in Automobile Fuel Consumption", DOT Report DOT-TSC-OST-74-40, December 1974.

[106] Pierce, "The Fuel Consumption of Automobiles", *Scientific American*, January 1975.

[107] Ambs, "Passenger Car Design Influences on Fuel Consumption and Emissions", AIAA paper 739113, August 1973.

[108] Data from Ford Motor Co. (unpublished).

[109] Nedley, "An Effective Aerodynamic Program in the Design of a New Car", SAE Paper 790724, June 1979.

[110] Marks, "Which Way to Achieve Better Fuel Economy?", Seminar at California Institute of Technology, December 1973.

[111] Marks and Niepoth, "Car Design for Economy and Emissions", SAE paper 750954, November 1975.

[112] West, *et al*, "A Technical Report of the 1975 Union 76 Fuel Economy Tests", SAE Paper 750670, August 1975.

These figures are in excellent agreement with data published by EPA[113]:

	Sq. Ft. Per Pound	Aerodynamic Fraction of Total Road Load HP 40 MPH	70 MPH
"Luxury car"	0.0042	29%	52%
"Standard car"	0.0049	31%	55%
"Compact"	0.0059	36%	58%
"Subcompact"	0.0070	40%	62%

These aerodynamic load fractions are spotted on the previous figure, and illustrate the magnitude of the vehicle size effect on the aerodynamic load contribution.

The EPA test does simulate the aerodynamic loading experienced by a vehicle, but only to the extent of aero drag encountered in still (windless) air. The instantaneous effect of winds upon in-use vehicles relative to the EPA test will, of course, be a function of wind speed, and wind direction relative to the vehicle. For purposes of estimating wind effects on overall nationwide fuel economy, we must expect a uniform 360° distribution of wind direction; this does not mean that all wind effects cancel out, however. DOT[97] has analyzed the aerodynamic effects of wind direction at a constant vehicle speed of 55 mph and concluded--as shown in the next figure--that losses at unfavorable wind angles significantly outweigh gains at favorable angles. The relative areas under these curves correspond to ratios of energy loss to energy gain of 2.2 to 1 (at 10 mph wind) to 2.4 to 1 (at 20 mph wind). So a vehicle exposed to winds from all angles still suffers a net energy penalty due to aerodynamic losses.

DOT also estimated the excess fuel consumption corresponding to these net wind losses at 55 mph, which fuel penalty (we will assume) applies to highway driving conditions. For city driving, the net wind penalty is less due to lower speeds. For the EPA City cycle, of which some 25% of miles traveled are affected similar to DOT's calculated 55 mph effect,

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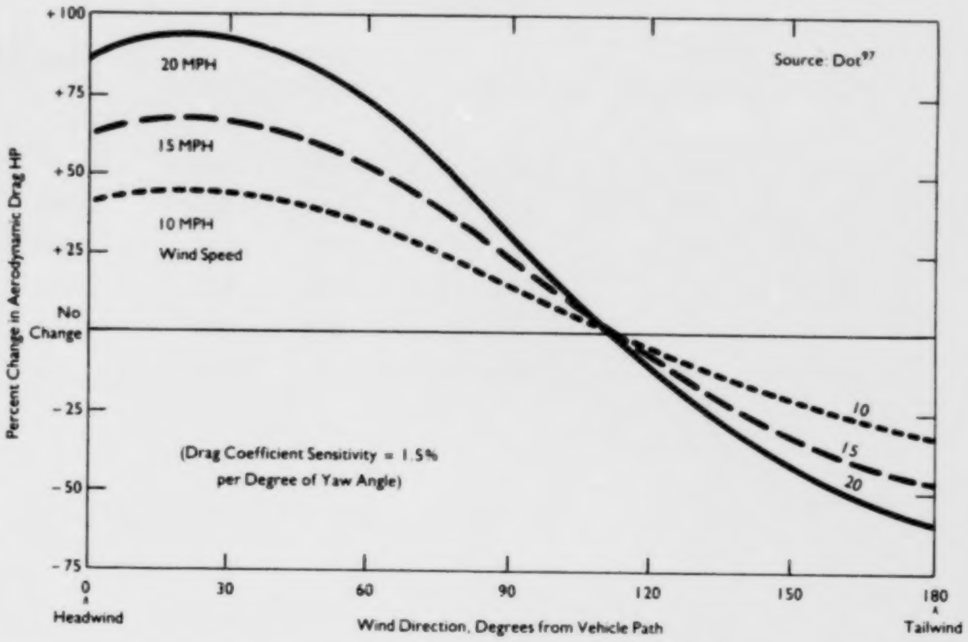
[113] U.S. Environmental Protection Agency, "Factors Affecting Automotive Fuel Economy", September 1975.

FIGURE 26. Effect of Wind on Vehicle Aerodynamic Drag at 55 MPH



there would be a net wind penalty about 20% as large as the highway penalty. Further, from the data presented earlier, smaller cars are influenced more strongly than larger ones by aerodynamic effects.

Using all of these factors and DOT's distribution of wind speeds, estimated wind-related shortfalls are 2-3%, depending on car size, as given in the following table.

It should be pointed out that the sensitivity of the calculation to actual road conditions is not well established in the area of in-use C_D. Most calculations are based on C_D yaw angle sensitivity, typically from wind tunnel tests. Whether the C_D sensitivity to yaw angle will remain the same for future cars, and how well the C_D and C_D/yaw angle data obtained from wind tunnels actually simulate in-use conditions such as flow field structure and the effects of nearby vehicles, is not known.

Wind Speed Distribution and Estimated MPG Effect (360°)

Wind Speed, MPH	% of VMT[a]	MPG Relative to EPA MPG[b] City: Small Car	Large Car	Highway: Small	Large	Combined City/Highway Small	Large
≤3	16	1.000	1.000	1.000	1.000	1.000	1.000
4-7	28	.996	.997	.981	.985	.992	.993
8-12	30	.986	.989	.938	.952	.968	.975
13-18	18	.979	.984	.903	.925	.950	.961
19-24	6	.971	.978	.870	.900	.931	.948
≥25	2	.962	.971	.828	.868	.908	.930
VMT-Weighted Average:	9 mph					.973 (Shortfall = 2.7%)	.979 (Shortfall = 2.1%)

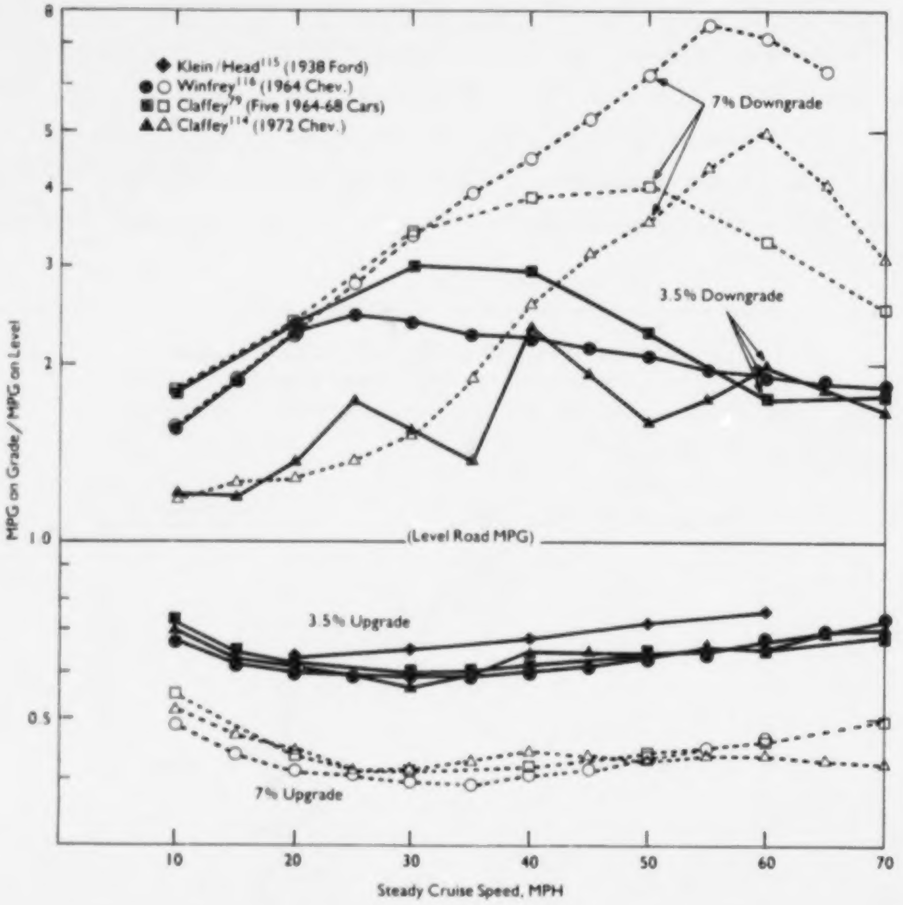
---

[a] From Ref. 97; EPA test wind speed = 0 mph:
>>84% of VMT at wind speeds greater than EPA

[b] Reference wind speed = 0 mph;
City Sensitivity, Small Car, -0.13% per mph wind
Large Car, -0.10% per mph wind
Highway Sensitivity, Small Car, -0.62% per mph wind
Large Car, -0.48% per mph wind

d. Road Gradient: There is an underabundance of test data on the effect of grades on fuel economy, and all of it is for steady cruise conditions. As depicted in the following figure, it is clear that grade has a dramatic MPG influence.

FIGURE 27. Effect of Road Gradient on Fuel Economy



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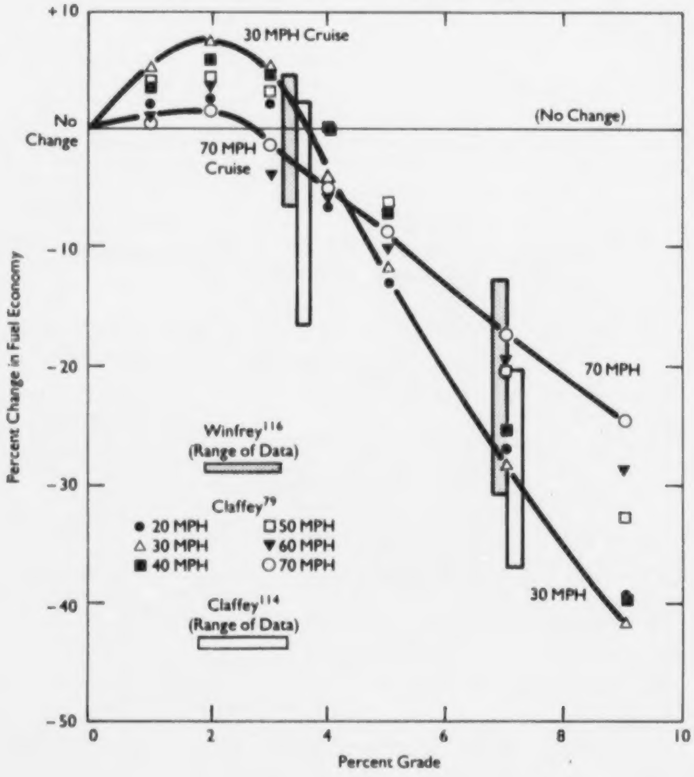
[114] Claffey, "Passenger Car Fuel Conservation", DOT Report FHwA-PL-77009, January 1977.

[115] Klein and Head, "The Effect of Surface Type, Alignment, and Traffic Congestion on Vehicular Fuel Consumption", Oregon State Highway Dept. Technical Bulletin No. 17, April 1944.

[116] Winfrey, "Economic Analysis for Highways", International Textbook Co., 1969.

The data are fairly consistent with regard to upgrades, because climbing an incline is very much a straightforward "brute force" mechanical matter. The data for downgrades are quite scattered, since specific engine and vehicle characteristics such as idle speed, compression ratio, aerodynamics, and axle ratio come into play when descending an incline. As in the case of wind, it must be assumed that over a period of time, travel up and down grades will balance out. But again in this case, the positive and negative MPG effects do not usually cancel. As shown in the next figure, one study suggests that for small gradients (less than 3.5%), fuel saved when descending overcompensates for excess fuel consumed when ascending, giving a small net benefit in overall gas mileage. For higher gradient values, the situation reverses, and there is a net MPG penalty which grows worse with increasing grade.

FIGURE 28. Effect of Road Gradient on Fuel Economy
(Miles Traveled Up = Miles Traveled Down)



The estimated nationwide effect of road gradient is a 2% MPG shortfall, when the distribution of grades is combined with the MPG factors derived from these data, as given in the following table.

Gradient Distribution and Estimated MPG Effect
(Miles Traveled Up = Miles Traveled Down)

		MPG Relative to EPA MPG[b]		
Grade, %	% of VMT[a]	City	Highway	Combined City-Highway
<0.5	35	1.000	1.000	1.000
0.5-1	20	1.000	1.000	1.000
1-2	15	1.000	1.000	1.000
2-3	10	1.000	1.000	1.000
3-4	8	.990	.980	.985
4-5	6	.920	.927	.923
5-6	4	.844	.878	.859
>6	2	.730	.807	.762
VMT-Weighted Average:	1.6% grade			.981 (Shortfall =1.9%)

---

[a] from Ref. 97; EPA test excludes grade simulation;
All of VMT occurs at grades greater than EPA conditions

[b] Reference grade = 0%;
Sensitivities above 3% grade per Claffey[79]; no net MPG effect assumed below 3% grade.

e. Road Surface and Condition: The limited number of data sources reviewed are in significant disagreement on the magnitudes of fuel economy penalties of less-than-ideal road surfaces; this may be due to the wide variances in actual characteristics that can exist for a given "classification" of road type. The table below summarizes these data.

Effect of Road Surface and Condition on Fuel Economy
(All values shown are loss in steady-cruise MPG relative
to dry, well-maintained concrete or asphalt)

	20 mph	30 mph		40 mph		50 mph	
A. Dry Surfaces	Claffey[79,114]	Claf[79]	K&H[115]	Claf	K&H	Claf	K&H
Concrete w/cracks, settling			1%		2%		3%
Asphalt, broken & patched	5%	17%	2-3%	25%	0-4%	33%	0-5%
Compacted Gravel	12-16%	21-22%	5-15%	36%	5-17%	41%	5-18%
						(Winfrey[116] 17%)	
Loose Gravel			5-21%		19-23%		21-27%
Earth			9-21%		10-21%		10-24%
Loose Sand	22%	29%		42%		50%	
B. Wet Surfaces (K&H)							
Asphalt, good condition			1-4%		0-5%		0-5%
Concrete			3%		3%		2%
Compacted Gravel			11-20%		11-22%		12-24%
Earth: Soft several inches	43%						
Axle-deep mire	65%						
C. Snow-Covered (Claffey[117])							
Hard-packed base	19-23%	14-17%		10-12%		6-9%	
New snow cover, 1/2"	26%	22%		17%		11%	
3/4"	30%	24%		19%		15%	
1"	32%	26%		22%		19%	
1 1/2"	34%	31%		29%		25%	
2"	38%	35%		32%		31%	

There is also the possibility that vintage of the test vehicles has some bearing on the data: Reference 115 employed pre-1940 autos, while References 79, 114 and 117 used models from the late 1960's and early 1970's in their tests.

Recent research[118], which considers not only frictional factors but the behavior of the vehicle suspension system, indicates that road roughness causes power consumption penalties which imply increases in *aerodynamic* drag, along with rolling resistance. This concept could explain why, in the previous table, percentage MPG losses appear to *increase* with vehicle speed for those conditions (broken pavement, gravel, etc.) involving surface *roughness* or macrofriction, but percentage losses *decrease* with speed on new snow, which is more of a purely microfrictional phenomenon. This is not to suggest that all of the macrofrictional penalty *is* an aerodynamic effect: although some roughness-induced losses due to vehicle pitch and yaw, and increased wheel-well turbulence, would in fact *be* aerodynamic, other losses involving the suspension system *behave as though* a drag coefficient increase had occurred.

The scatter in the data on MPG effects leaves wide margins for assessing penalty points for various road surfaces; in addition, we are not in possession of good data on the relative distribution of *vehicle-miles* traveled among various surface classifications. Hence our evaluation of the nationwide MPG shortfall due to road surfaces involves some estimation. Using known distributions of *roadway miles* from DOT, we have made our own assumptions for relative traffic flow among those road categories to estimate the VMT distribution. These figures, and assumed MPG penalties, are given in the next table. These estimates and assumptions yield a 4% shortfall.

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[117] Claffey, "Passenger Car Fuel Consumption as Affected by Ice and Snow", Report sponsored by Task Force on Application of Economic Analysis to Transportation Problems, 1971.

[118] Velinsky and White, "Increased Vehicle Energy Dissipation Due to Changes in Road Roughness with Emphasis on Rolling Losses, SAE paper 790653, June 1979.

Estimated Road Surface Effect on Fuel Economy

	% of Roadway Miles[a]	% of Vehicle Miles[b]				MPG Relative to EPA MPG[c]		
Road Surface		Total	Dry	Wet	Snowy	Dry	Wet	Snowy
Unsurfaced	18.2	1.8	1.2	0.4	0.1	.80	.70	.65
Gravel, Slag, etc.	31.1	9.7	6.7	2.4	0.6	.85	.82	.80
Low-Load Asphalt	27.3	30.2	20.9	7.4	1.8	.96	.95	.90
Concrete and Hi-Load Asphalt	23.4	58.3	40.4	14.3	3.6	1.00	.97	.93

VMT-Weighted Average MPG Factor: 0.956 (Shortfall = 4.4%)

---

[a] Based on DOT data[119]

[b] EPA test simulates a dry, good-condition paved road; ∿60% of VMT occurs on poorer surfaces. The VMT distributions are EPA estimates; "wet" and "snowy" VMT fractions are based on precipitation-data from NOAA[120], and on degree-days data from ASHRAE[121].

[c] MPG penalties estimated from data presented earlier.

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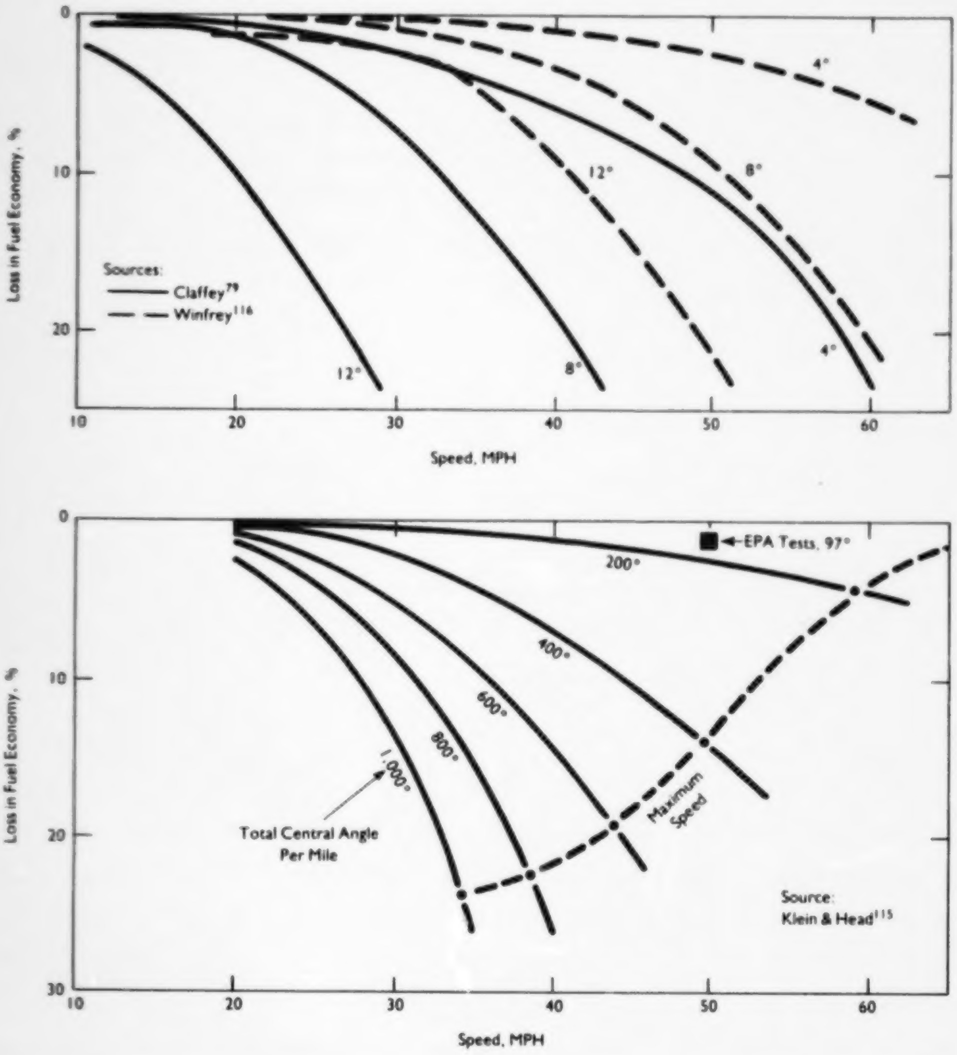
[119] U.S. Department of Transportation, "Highway Statistics 1977", Report FHwA-HP-HS-77, 1979.

[120] U.S. National Oceanic and Atmospheric Administration, Comparative Climatic Data, annual.

[121] American Society of Heating, Refrigerating and Air-Conditioning Engineers, ASHRAE Handbook, 1978.

f. Road Curvature: Once more, available MPG sensitivity data on this influence are scarce, inconsistent, and limited to steady cruise operation, as summarized in the figures. Klein and Head[115] presented the important result that total central angle per mile uniquely determines the MPG penalty for a given vehicle speed, whether made up of many short, sharper curves or fewer, longer gradual curves.

FIGURE 29. Effect of Road Curvature on Fuel Economy



In the EPA's Dynamometer vs. Track Project, coastdown tests were run on both the straightaways and the curves of the test track to determine the relative road load values. The results differed with "car size", as listed in the table. The smaller cars were not equipped with power steering, and the larger cars were. The table also shows general fuel economy sensitivites to changes in 50 mph road load HP, and the resulting estimated MPG penalties for the curvature of this particular test track. This curvature is equivalent to traveling in an 0.9 mile diameter circle, and the MPG penalty is about 1%.

Effect of Road Curvature on Road Load and Fuel Economy
(97° Central Angle per Mile)

	Small Cars (Without Power Steering)	Large Cars (With Power Steering)
Increase in 50 mph RLHP[a]	2.2%	4.6%
Change in MPG per % Δ RLHP[b]		
City	-0.16%	-0.16%
Highway	-0.33%	-0.29%
MPG penalty, City	-0.36%	-0.75%
MPG penalty, Highway	-0.73%	-1.33%

[a] EPA Dyno/Track project coastdown tests

[b] *Ibid.* and Southwest Research[122]

A minimum estimate of the nationwide effect of curvature would use average trip lengths and average speeds from the travel characteristics computations in Appendix E, arriving at round trip average distances of 17.4 and 21.1

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[122] Martin and Springer, "Influence on Fuel Economy and Exhaust Emissions of Inertia, Road Load, Driving Cycles, and N/V Ratio for Three Gasoline Automobiles", Final Report, Task No. 9, EPA Contract 68-03-2196, June 1977.

miles, and average speeds of 31.7 and 33.2 mph for small cars and large cars, respectively. These values--together with the central angle per mile MPG sensitivity data from Klein and Head and the EPA tests--result in overall curvature MPG penalties of 0.07% for small cars and 0.12% for large cars. This is a minimum estimate, since greater circuity of round-trip travel will increase these penalties; however, we have no circuity data with which to make a more representative estimate.

g. Summary - Travel Environment Effects: The table below summarizes the estimated fuel economy effects of the travel environment factors analyzed:

Relative Fuel Economy Associated with Travel Environment Effects (EPA 55/45 MPG = 1.000)

	Total U.S. (VMT-Weighted)		Range for Individual Cars	
Factor	Small Cars	Large Cars	Best	Worst
Temperature	0.920	0.961	1.06	<0.69
Altitude	0.999	0.999	1.04	0.99
Wind	0.973	0.979	1.00	<0.83
Grade	0.981	0.981	>1.0	<0.60
Road Surface	0.958	0.958	1.00	0.35
Road Curvature	<0.999	<0.999	1.00	0.75
Cumulative Effect	0.840 (Shortfall = 16.0%)	0.882 (Shortfall = 11.8%)		

The cumulative effects shown are the products of the individual factors' effects. The "best" and "worst" values shown are not the possible extremes, nor even the extremes seen for individual test cars, but merely reminders of the order-of-magnitude effects when each factor takes on highly favorable or highly unfavorable values. It is important to note that the "best" conditions correspond to little or no improvement over the EPA values, but there is ample opportunity for a significant shortfall when any one or more of these factors is highly unfavorable. Put another way, the Travel Environment simulated by the EPA test is one that gives close to the best fuel economy of all possible Travel Environments.

2. Travel Characteristics

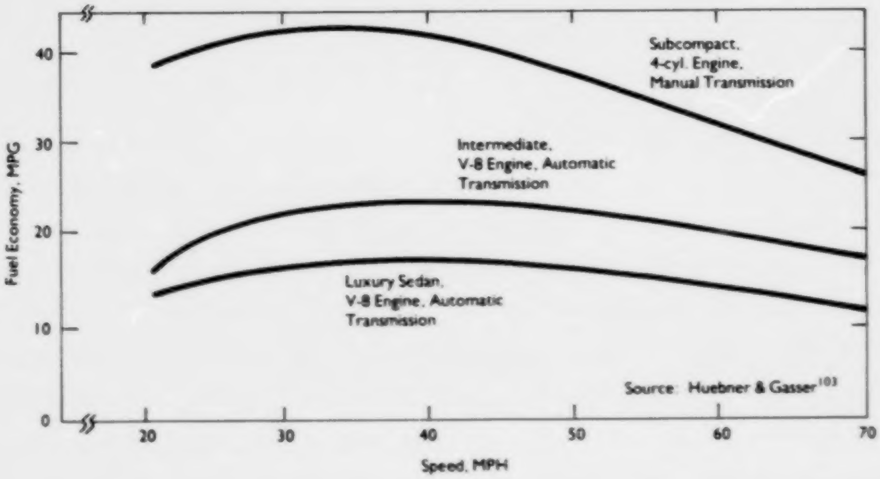
Travel characteristics which influence fuel economy in a quasi-instantaneous manner (that is, for a given trip or segment of a trip) include vehicle speed, stopping frequency, and acceleration intensity. Overlaid upon such effects are influences related to recent vehicle history: The extent to which the vehicle is warmed-up, which depends on distance traveled since being started, and the degree to which it had cooled down from previous travel.

These factors are usually interrelated: short trips generally involve higher stopping frequency and lower average speeds, and are influenced significantly by warmup effects; longer trips are generally faster, smoother, and less influenced by warmup.

a. Vehicle Speed: The dependence of fuel economy on vehicle steady cruise speed has long been recognized. Vehicle and engine size have also been noted for their dramatic effect on fuel economy over a wide range of speeds, as in the figure.

Because of this vehicle/engine dependence, the relative effect of speed alone can be seen more clearly through the use of normalized fuel economy, as shown in the next double figure, with MPG at 40 mph used as the

FIGURE 30. Fuel Economy Versus Cruise Speed for Three Vehicles



Source: Huebner & Gasser[103]

normalization base. The left-hand figure shows relative MPG:speed curves for data previously published by the DOT and the MVMA. The right-hand curves are from the EPA dyno/track project, and agree quite well with the general curve shape of the left-hand figure; the dyno/track curves also confirm that cruise speed affects fuel economy in about the same relative way whether measured on the dynamometer or on a test track.

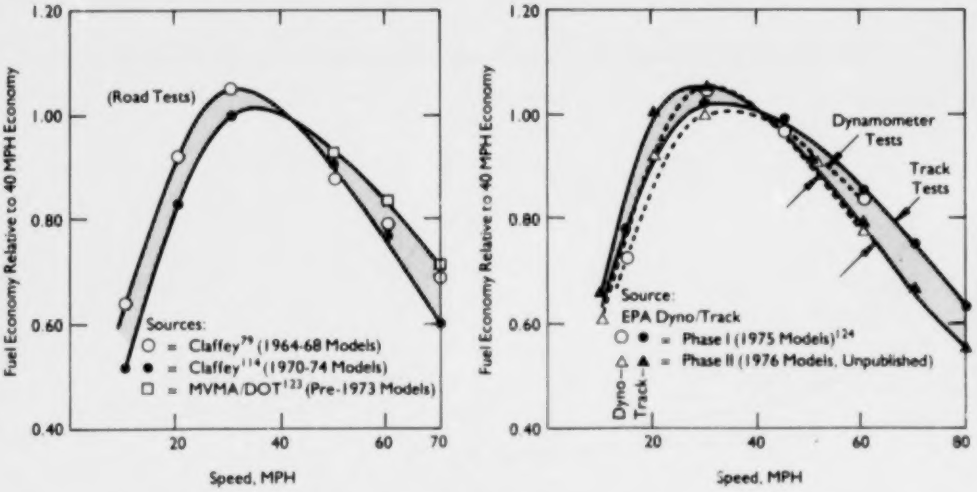


FIGURE 31. Effect of Speed on Fuel Economy—Steady Cruise

In actual driving situations, particularly in urban traffic, far less than half of travel time is spent cruising at steady speeds[125].

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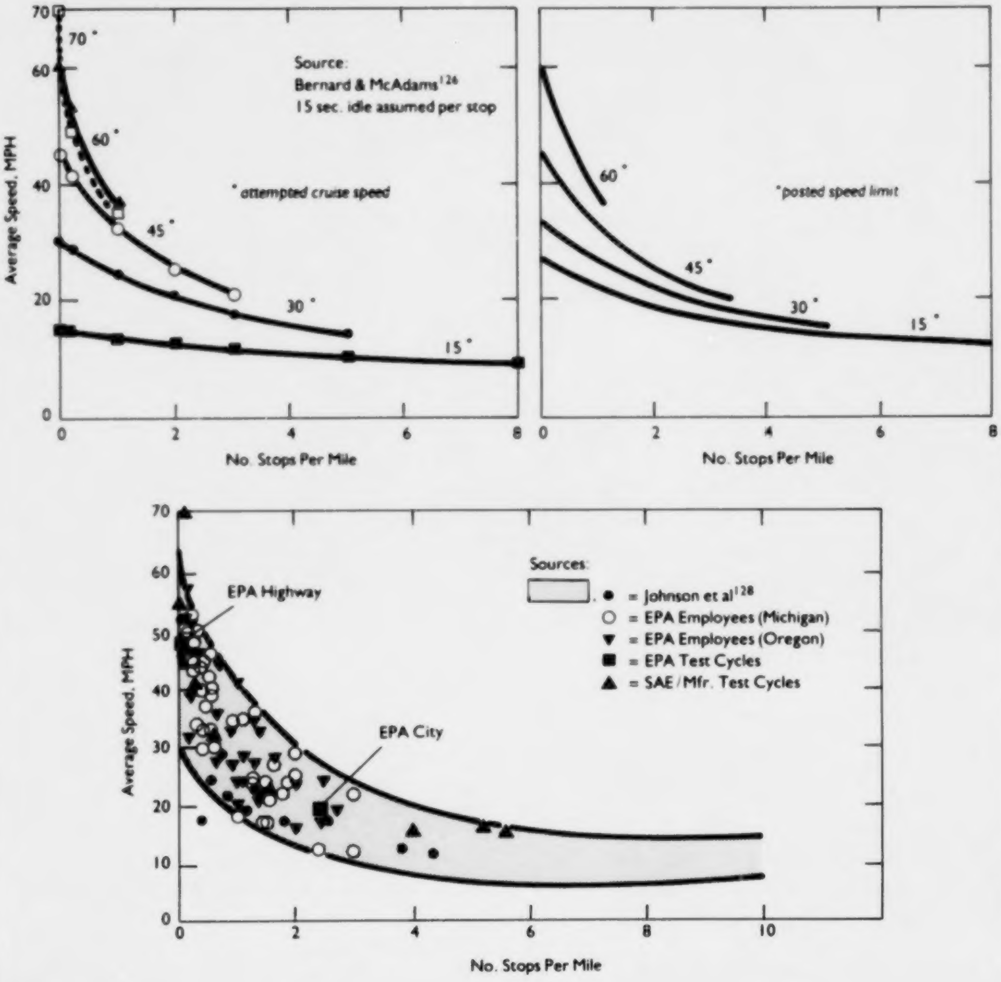
[123] Motor Vehicle Manufacturers Association, "Motor Vehicles and Energy", January 1974 (includes data from U.S. DOT Federal Highway Administration).

[124] Austin, "Passenger Car Fuel Economy -- Dynamometer vs. Track vs. Road", Report 76-1, Technology Assessment and Evaluation Branch, ECTD, EPA, August 1975.

[125] Scott Research Laboratories, "Vehicle Operations Survey", Final Report under Coordinating Research Council/EPA Project No. CAPE-10-68(1-70), December 1971.

Average speed in real-world traffic is determined by many, many factors; a thorough treatment of the subject would be burdensome here, since our primary concern is the fuel economy effect of average speed, not what causes average speed to be what it is. The relation between average speed, attempted cruise speed, and stopping requirements is of interest, however. Using nominal vehicle acceleration and deceleration characteristics derived from traffic survey data[126], the top left figure illustrates how stopping frequency affects average speed for specific attempted cruise speeds.

FIGURE 32. Relationship Between Average Speed and Stopping Frequency



Speed has been related to posted speed limits and other factors according to:

$$V = 20.5 + 0.433(PSL) - 0.407(NRE) + 0.115(OSC) + 0.0005(MSD)$$

[from Wortman, 1965, in Ref. 127]

where: V = mean spot speed, mph

PSL = posted speed limit, mph

NRE = number of roadside establishments per mile

OSC = percent out-of-state cars in traffic stream

MSD = minimum sighting distance, feet

If it is assumed that minimum free-flow speed, occurring when NRE, OSC, and MSD are all zero, is a conservative estimate of attempted cruise speed, the Wortman formula gives:

$$V_{attempted} = 20.5 + 0.433(PSL)$$

from which we see that attempted cruise speed exceeds posted limits, up to about 40 mph. Applying this to the data in the top-left figure, it is inferred that average speed in stop-and-go traffic is relatively independent of posted limits, and dependent mainly on stop frequency, as in the top-right figure. The lower figure depicts average speed/stop frequency relationships as observed in actual traffic[128] and in a recent survey of EPA employee home-to-work commuting trips[129]. Similarity of these data to the top right figure is obvious.

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[126] Bernard and McAdams, "Automobile Exhaust Emission Modal Analysis Model", EPA Report EPA-460/3-74-005, January 1974.

[127] Voorhies, et al, "Vehicle Operation, Fuel Consumption, and Emissions as Related to Highway Design and Operation", Interim Report prepared for FHWA, October 1977.

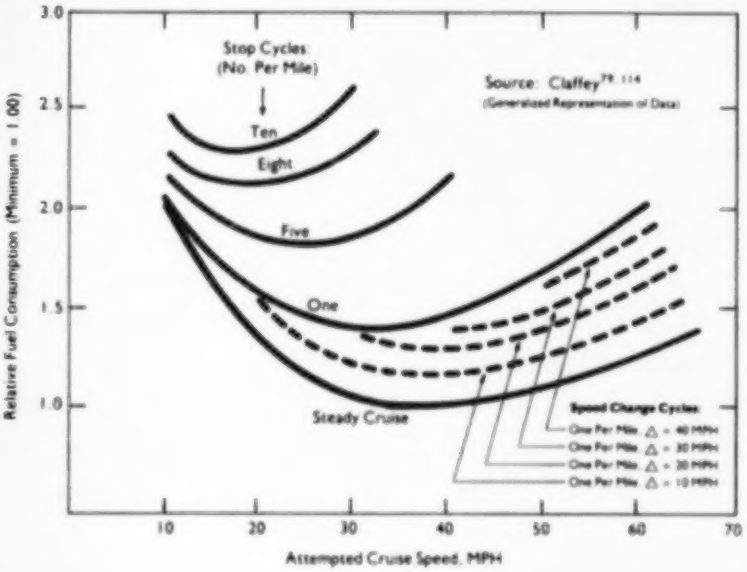
[128] Johnson, et al, "Measurement of Motor Vehicle Operation Pertinent to Fuel Economy", SAE Paper 750003, February 1975.

[129] Unpublished.

The lower graph in Figure 32 also shows specific average speed and stop frequency values for the EPA tests, auto manufacturers' proving-ground tests (some of which constitute the SAE road tests), and for specific road types, from expressways to shopping center parking lots.

The fuel consumption effects of slowdowns and stops have been investigated by Claffey[79,114] as a function of attempted cruise speed. An example of this data appears in the following figure.

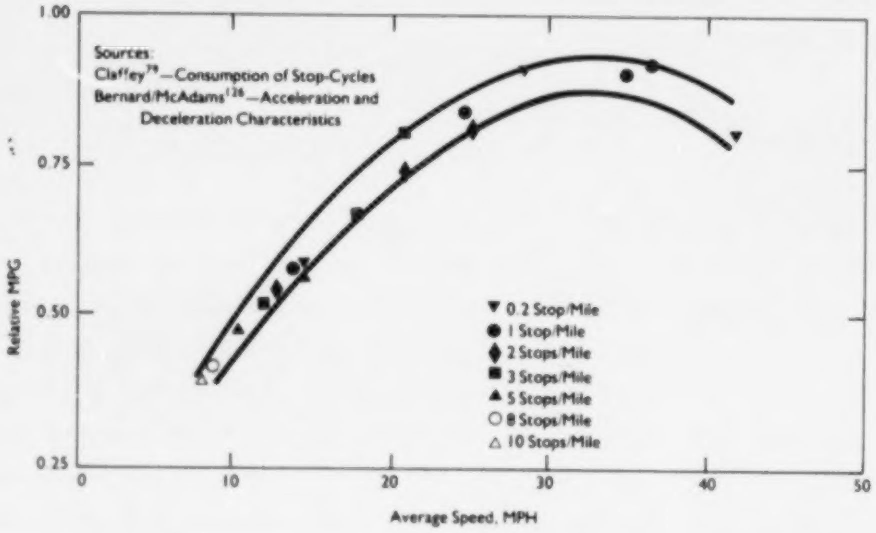
FIGURE 33. Effect of Stops and Speed Variations on Fuel Consumption



Source: Claffey[79,114]
(Generalized Representation of Data)

When this type of behavior is combined with speed/stop frequency data, the pattern in the next figure results: for cyclic driving, relative fuel economy is essentially a function of average speed only, virtually independent of the particular stop frequency and attempted cruise speed that produced that average speed.

FIGURE 34. Relative Fuel Economy vs. Average Speed



Sources:
Claffey[79]—Consumption of Stop-Cycles
Bernard/McAdams[126]—Acceleration and Deceleration Characteristics

This relationship has been studied extensively by Evans et al[130], and can be expressed in terms of fuel consumption:

$$G = j + k/V \qquad \text{(for speeds} \leq 40 \text{ mph)}$$

where G is fuel consumption per unit distance, V is average speed, and j and k are constants. The constant j is proportional to vehicle weight (according to $j = 9 \times 10^{-6} W$, where W = pounds, for the nine 1973-76 test cars in Ref. 130), and the constant k is proportional to the engine's idle fuel flow rate (k = 1.25I, where I = gallons/hour).

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[130] Evans, et al, "Gasoline Consumption in Urban Traffic", SAE paper 760048, February 1976; "Automobile Fuel Economy on Fixed Urban Driving Schedules", General Motors Research Report GMR-2453, June 1977; "Urban Traffic, Fuel Economy and Emissions--Consistency of Various Measurements", SAE paper 780934, November 1978, [See also: Chang, Evans, et al in Transportation Research Record 599, 1976, at 25.]

EPA[131] has found I to be dependent upon engine cubic inch displacement ($I = 0.27 + .0017(C)$, where C = cubic inches). Thus a vehicle weighing "W" pounds, with an engine of "C" cu. in. displacement, traveling at "V" miles per hour (average), will consume "G" gallons per mile, in cyclic driving, according to:

$$G = 9x10^{-6}(W) + \frac{.34 + .002(C)}{V} \qquad [V \leq 40 \text{ mph}]$$

This equation is only valid for the types of vehicle/engine combinations from which it was derived. Changes such as fuel shutoff at idle, or significant changes in CID-to-weight ratio, would necessitate modification of the equation. In addition, this equation is applicable only up to average speeds of approximately 40 mph, after which cruise conditions are approached and higher speed operation results in decreasing fuel economy. The only cyclic-driving variables other than average speed which have any significant influence on fuel consumption (for warmed-up vehicles) are related to acceleration and deceleration intensities[132]. Traffic network studies[133] similarly show average speed to be by far the most significant determinant of vehicle fuel consumption.

The next figure compares steady cruise fuel economy and generalized cyclic-driving fuel economy, for cars from several recent model years.

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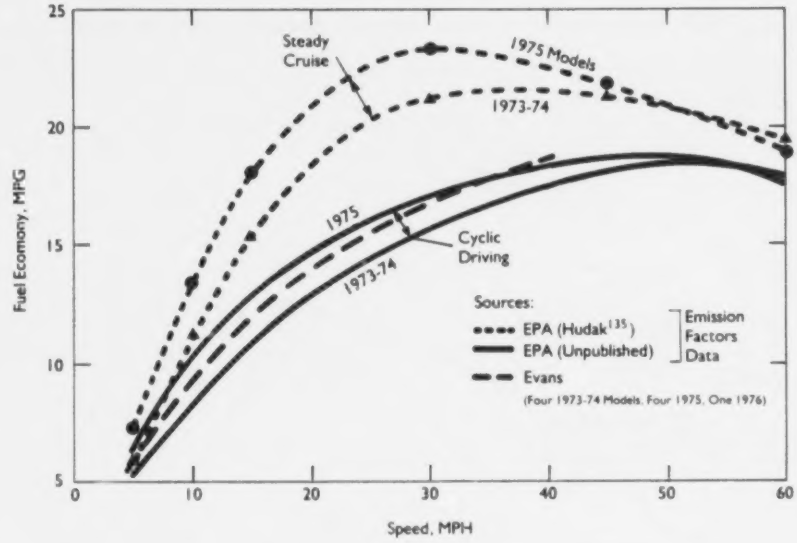
[131] Barth, "Idle Fuel Consumption in Passenger Cars", Report 75-29, Technology Assessment and Evaluation Branch, ECTD, EPA, July 1975.

[132] Evans, et al, "Multivariate Analysis of Traffic Factors Related to Fuel Consumption in Urban Driving", General Motors Research Publication GMR - 1710, May 1976. [See also: Evans, et al in Transportation Science, Vol. 10, No. 2, May 1976, at 205.]

[133] Honeywell Traffic Management Center, "Fuel Consumption Study - Urban Traffic Control System (UTCS) Software Support Project", Report FHwA-RD-76-81, February 1976.

The EPA curves are from EPA Emission Factors production car dynomometer data, with the cyclic curves generated by Ref 126's Modal Analysis Model and driving cycles synthesized after the methods in Ref. 134. The agreement of the cyclic-driving simulations with the Evans road test data[130] is quite good up to 30 mph average speed.

FIGURE 35. Fuel Economy vs. Speed, Cruise and Cyclic Driving (Generalized)



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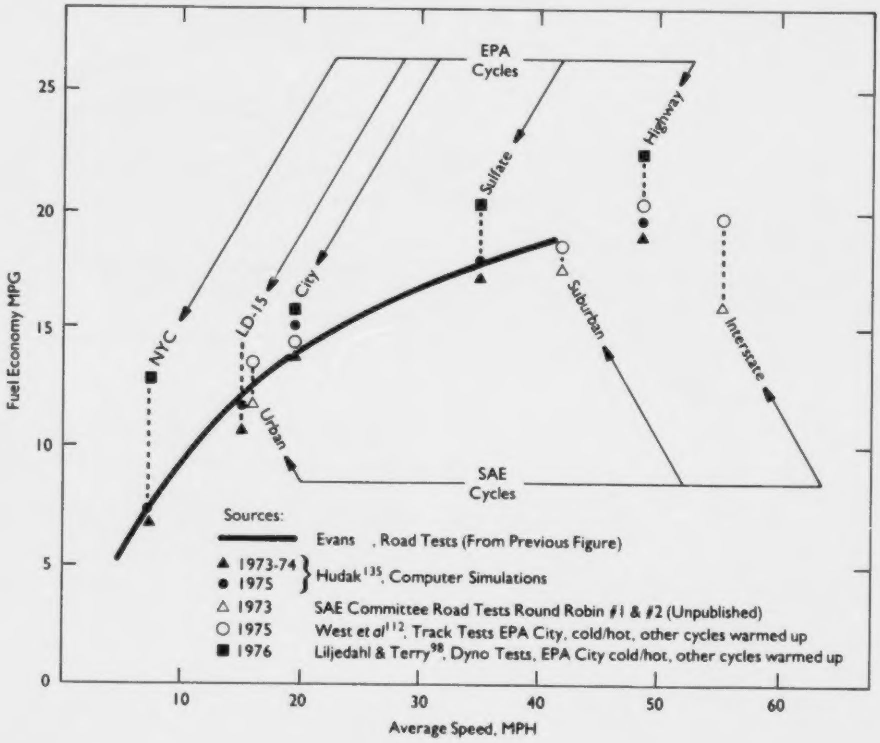
[134] Smith and Weston, "A Technique for Generating Representative Chassis Dynamometer Test Cycles", APCA Paper 72-165, June 1972.

[135] Hudak, "Effects of Driving Cycle Average Speed and Acceleration on Emissions and Fuel Economy: A Modeling Study", Characterization and Analysis Branch, ECTD, EPA, May 1979.

In the next figure, fuel economy for specific test cycles is shown. As in the previous figure, the fuel economy:average speed equation's behavior is shape-wise consistent with MPG results of these driving cycles, for road tests, dynamometer tests, and computer simulations.

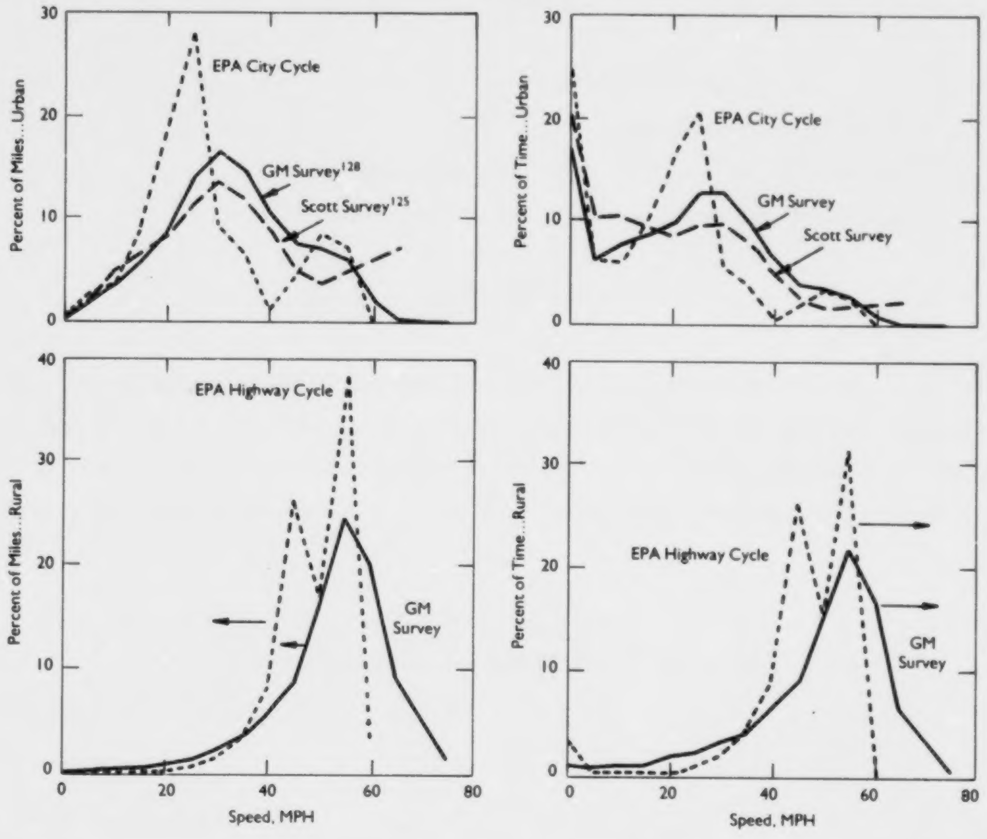
Model year differences implied by this and the previous figures may or may not be accurate; the vehicle mixes of the various data sources were intended to be representative, but they are not exactly the same.

FIGURE 36. Fuel Economy vs. Average Speed, Specific Test Cycles



The distributions of vehicle speeds from actual traffic surveys are compared with the EPA cycles' speed distributions in the next figure. The EPA City cycle expends a higher percentage of time and mileage at speeds below 30 mph and lower percentages above 30 mph, than the survey data. The EPA Highway cycle is similarly biased toward lower speeds.

FIGURE 37. Comparison: Speed Characteristics, EPA Cycles vs. Traffic Surveys



If speed differentials were independent of other travel characteristics, the urban speed distributions would yield fuel economy better than the EPA City cycle, and the highway distributions would yield fuel economy poorer than the EPA Highway cycle, principally due to the MPG reduction effect of high-speed driving.

b. Influence of Traffic Volume: The speed characteristics of a vehicle in a traffic stream are obviously influenced by that stream. One relevant expression for that influence is:

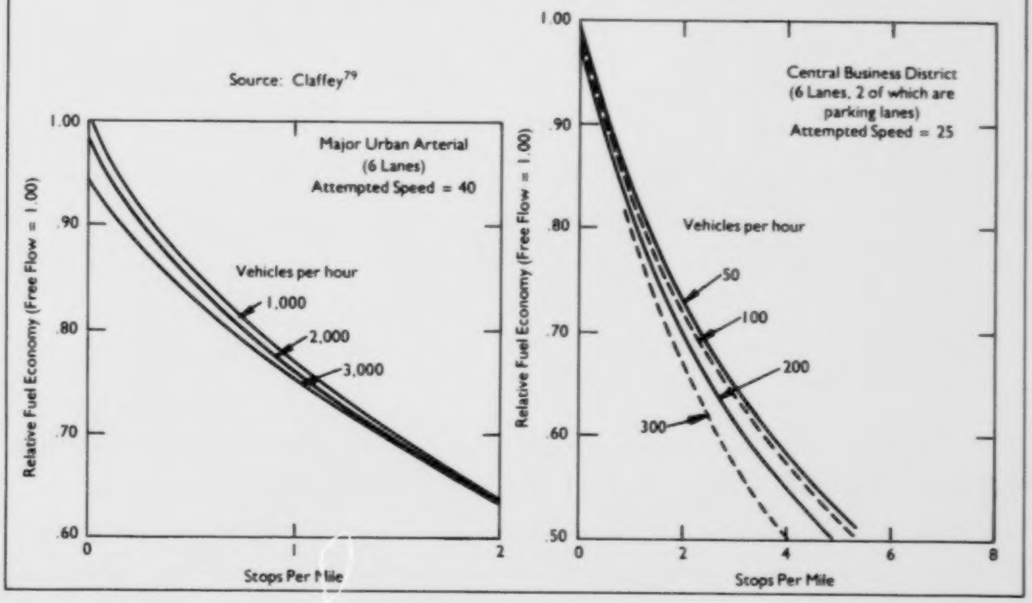
$$V = V_f \left(1 - {}^{d}/_{d_j}\right)$$ [from Greenshields, 1930, in Ref. 127]

where: V = average vehicle speed
V_f = free-flow speed
d = vehicle density, vehicles per lane-mile
d_j = jam density, ∿ 250 vehicles per lane-mile

Note that "V" approaches zero as "d" approaches jam density.

Claffey[79] has estimated the combined effects of traffic density and stopping frequency for two urban road types, as shown in the next double figure. These estimates indicate that fuel economy is influenced more by stopping frequency than by traffic volume. That is, if traffic volume changed without affecting

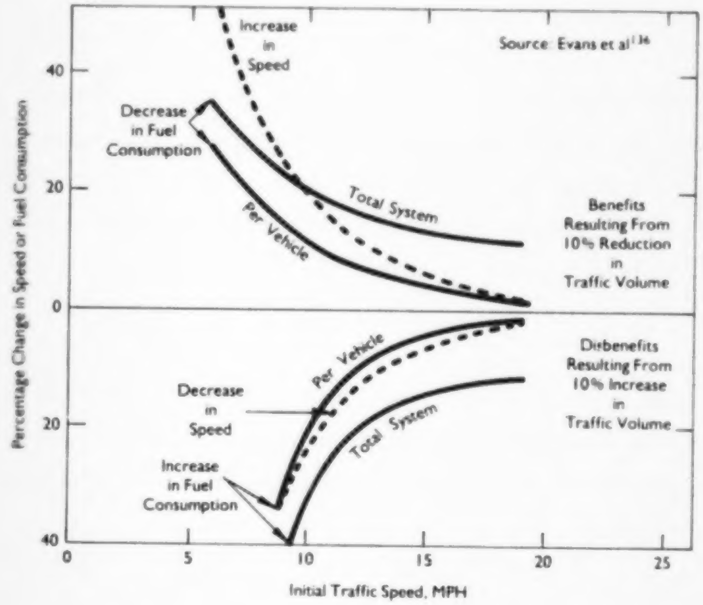
FIGURE 38. Effect of Traffic Volume on Fuel Economy



Source: Claffey[79]

stop frequency, MPG would be affected only to a second-order degree. When changes in traffic volume are evaluated as to total effect on the stream, including stop frequencies, however, the impact on average speed and fuel consumption can be dramatic. The next figure illustrates this. When vehicle flow decreases, stream average speed goes up, and the remaining vehicles operate at better fuel efficiency. Hence a 10% drop in traffic volume can pay off in a fuel consumption reduction much greater than 10%. The negative effects of traffic flow increases are compounded in the same way.

FIGURE 39. Effect of Traffic Volume Changes on Fuel Economy and Flow Speed



Source: Evans et al[136]

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[136] Evans et al, "A Simplified Approach to Calculations of Fuel Consumption in Urban Traffic", GM Research Report GMR-2181, August 1976.

This would suggest that a change of traffic controls, in an attempt to increase vehicle average speed and hence fuel economy, could show no net benefit if it attracts more vehicles into the stream. A reduction in traffic volume, on the other hand, guarantees fuel-saving results. It must be pointed out that the above discussion and statements only apply to traffic flow with average speeds less than about 40 miles per hour. The results cannot be extrapolated to significantly higher speeds.

c. Trip Length: Two effects closely related to trip length are of prime interest to fuel economy: average speed, and vehicle warmup.

(1) Trip Average Speed - Report No. 8 of the DOT Nationwide Personal Transportation Study (NPTS)[137] relates elapsed times and trip lengths for home-to-work commuting, and has been a principal reference for analyses of trip length and average speed in the literature[138,139].

There are three problems with literal use of the NPTS data. The first, as pointed out by Joksch and Reidy[139], is that the data are based on a questionnaire, and the questions may have elicited overestimated travel times and correspondingly low travel speeds. In particular, total reported trip times are believed to represent person time, from residence door to workplace door, rather than vehicle operating time.

Joksch and Reidy observed that the difference in travel time between trips of various lengths gives an indication of instantaneous speed. The next figure shows this kind of interpretation of the NPTS data.

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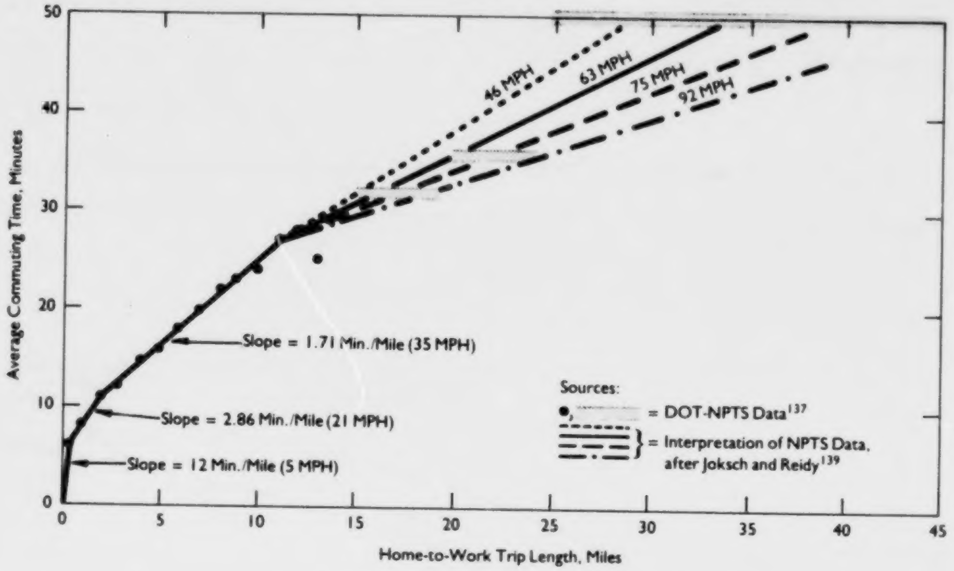
[137] Svercl and Asin, "Nationwide Personal Transportation Study, Home-to-Work Trips and Travel, Report No. 8", DOT/FHwA, August 1973.

[138] Austin and Hellman, "Passenger Car Fuel Economy as Influenced by Trip Length", SAE paper 750004, February 1975.

[139] Joksch and Reidy, "Categorization and Characterization of American Driving Conditions (Phase I)", DOT Report DOT-TSC-NHTSA-78-41, November 1978.

FIGURE 40. Home-to-Work Commuting Time and Implied Average Speeds

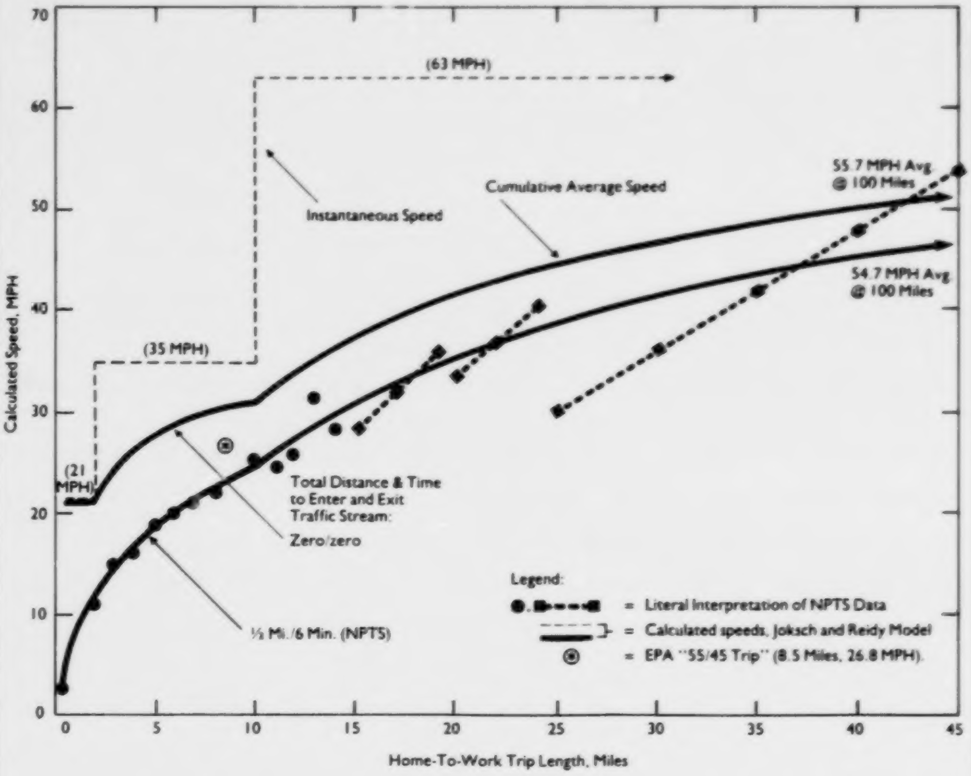


Trips between 1/2 mile and two miles in length are associated with a 21-mph slope, trips between two and ten miles in length a 35-mph slope, and longer trips a high-speed slope (There is some uncertainty about the latter slope due to the way the NPTS data is presented, but Joksch and Reidy argue plausibly for a 63-mph interpretation).

Applying these data to actual trip geometries, and assuming a trip of length "X", the average commuter spends the first (and last) 1/4 mile entering and exiting a 21 mph traffic stream, the next 3/4 mile (and the 3/4 mile segment from X-1 to X-1/4 miles) at 21 mph average, the next 4 miles (and the 4-mile segment from X-5 to X-1 miles) at 35 mph, and the middle 5 to X-5 miles at 63 mph.

The cumulative average speed for a given trip can be calculated from these building blocks, and of course agrees with the NPTS data if one accepts the data's suggestion that it takes 1/2 mile and six minutes total to enter and exit the stream: this is shown in the lower curve in the next figure. The maximum cumulative average speed that can be calculated with this model (assuming that entrance into, and exit from, the 21 mph stream are instantaneous) is represented by the top curve. This interpretation predicts home-to-work average speeds six to eight mph faster than literal interpretation of the NPTS data.

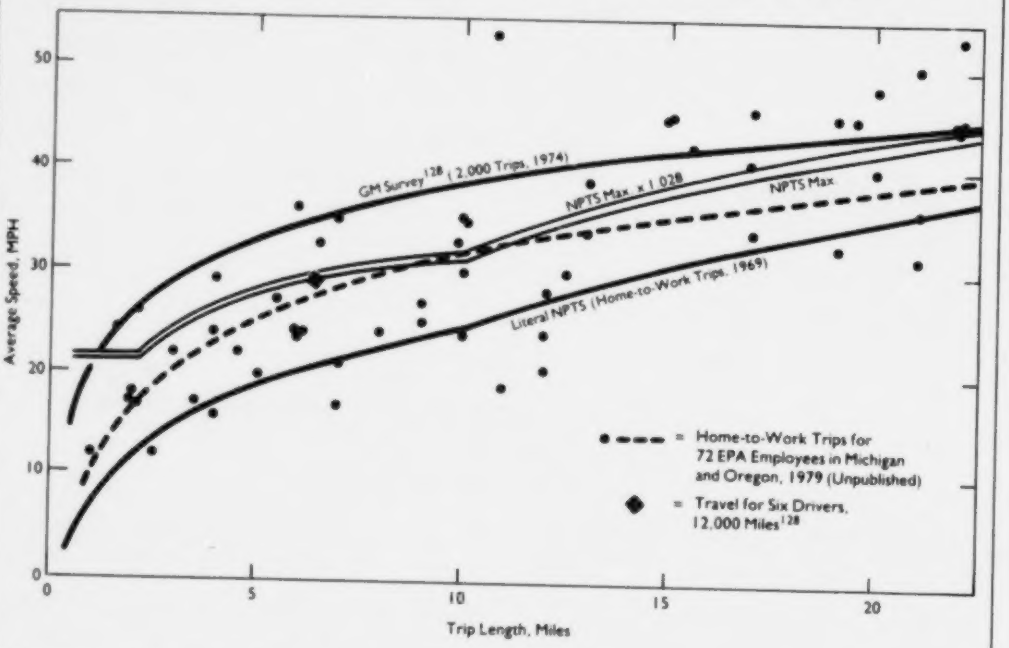
FIGURE 41. Average Speed vs. Trip Length in 1969: A Function of Data Interpretation



The second problem with the data is that it represents only work-related commuting trips. The same NPTS report indicates that work-related travel occurs predominantly in hours of the day when traffic density is high, the work travel being in fact a prime contributor to that traffic density. Appendix D is a computation of the 24-hour average speeds for both work and non-work travel, considering the different distributions of those respective types of trips among periods of varying traffic density. From that analysis, it would be estimated that non-work trips are 4.2% faster than work trips, and all travel combined is 2.8% faster than work trips alone.

The third problem is that the NPTS data applies to travel in 1969. More recent surveys of the characteristics of relatively short trips show average trip speeds to be significantly higher than [literal interpretation of] the NPTS data. The next figure compares the two NPTS interpretations with the results of two such surveys; the literal NPTS interpretation clearly underestimates average trip speeds relative to the surveys, while the maximum interpretation is quite a good fit to the data.

FIGURE 42. Data from Mid-1970's Surveys of Average Speed vs. Trip Length



(2) Warmup Effects - It has been well documented [140-143] that vehicles achieve poorer fuel economy when started "cold" than when fully warmed up. The table below gives relative instantaneous fuel economy (MPG ÷ fully warm MPG) at specific operating times after start, for various pre-start soak times, in the first part of the EPA city cycle[143]:

Relative Instantaneous Fuel Economy

	Minutes after Start:				
Soak time, hours	1.05	2.10	3.15	4.20	8.42
1/2 or less	1.000	1.000	1.000	1.000	1.000
1	0.966	0.961	0.986	0.969	1.024
2	0.862	0.895	0.974	0.952	0.977
4	0.726	0.846	0.894	0.902	0.960
8 or more	0.592	0.739	0.772	0.845	0.929
Miles Traveled:	0.22	0.67	0.82	1.67	3.59

In similar tests, relative instantaneous EPA City MPG values were measured for both dynamometer operation and operation on a test track[144], after soaks of eight hours or more:

Relative Instantaneous Fuel Economy

	Minutes after Start:				
Test Site	2.33	5.67	8.42	17.33	22.87
Laboratory (Dyno)	0.658	0.884	0.934	0.979	1.022
Test Track	0.657	0.872	0.929	0.972	0.987
Miles Traveled:	0.68	2.65	3.59	6.34	7.50

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[140] Scheffler and Niepoth, Op. Cit. (81)

[141] U.S. Environmental Protection Agency, "A Report on Automotive Fuel Economy", October 1973.

[142] Matula, "Emissions and Fuel-Economy Test Methods and Procedures", Consultant report to the National Academy of Sciences, September 1974.

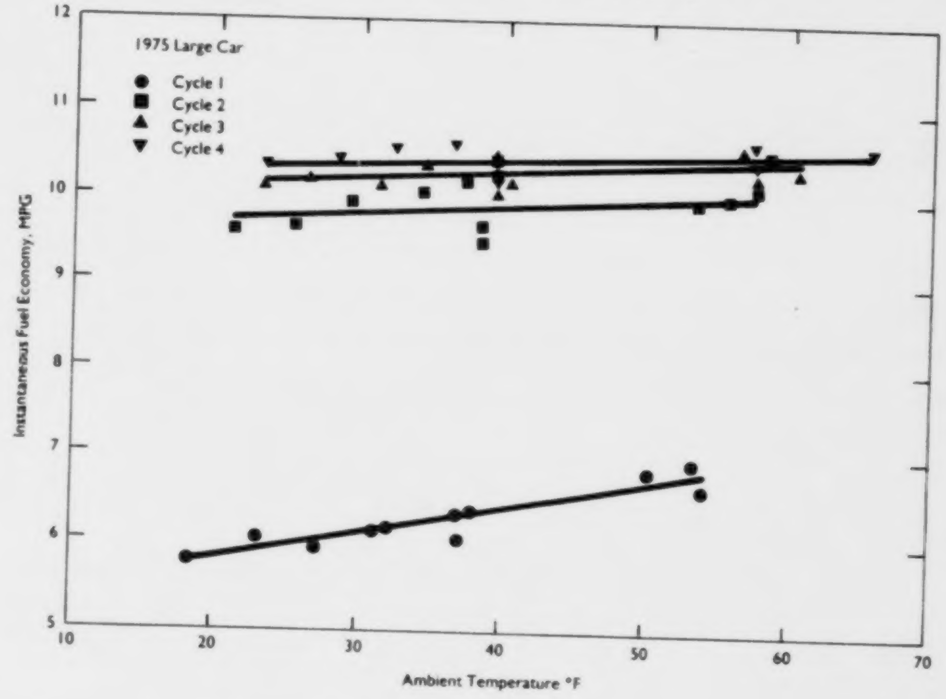
[143] Srubar, et al, "Soak Time Effects on Car Emissions and Fuel Economy", SAE paper 780083, March 1978.

[144] EPA, Op. Cit. (87)

This indicates that the fully-warmed up (FWU) condition has essentially been reached by the end of the 7.5-mile EPA City Cycle.

These findings are comparable to cold start data from road course tests[145] using the SAE Urban driving cycle; an example of that data is shown in the next two figures plotted as a function of ambient temperature. The first graph shows low fuel economy for the first run of this 2-mile cycle, and progressively improved fuel economy in succeeding runs. The second graph gives the fuel economy values for the first 1/2 mile and the next 1-1/2 miles of the first cycle.

FIGURE 43. Fuel Economy Data, SAE Urban Cycle[145]



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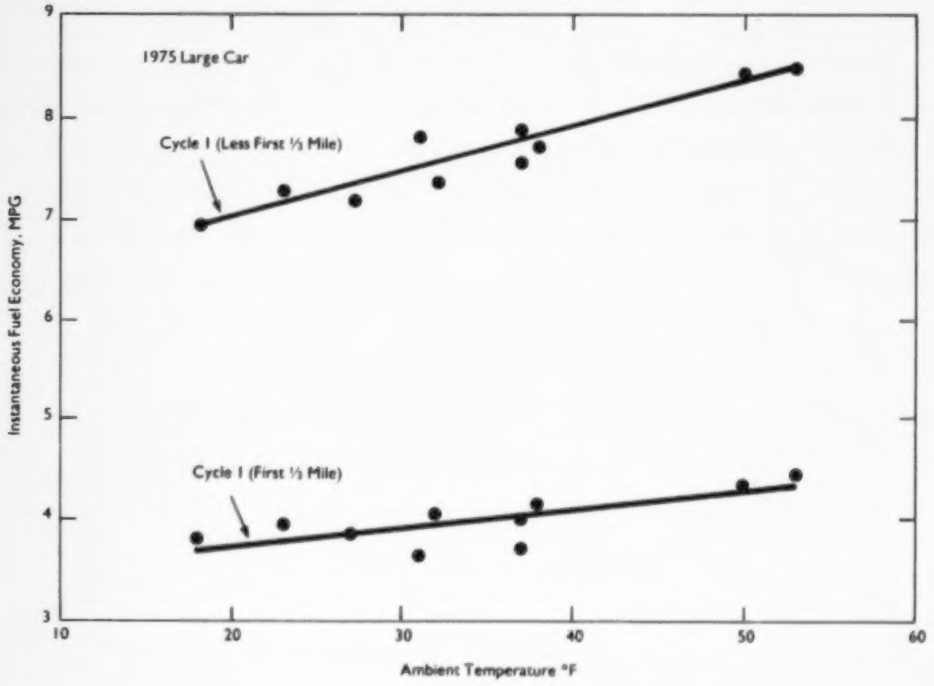
[145] Mobil Oil Co., Op. Cit. (85)

FIGURE 44. Fuel Economy Data, SAE Urban Cycle



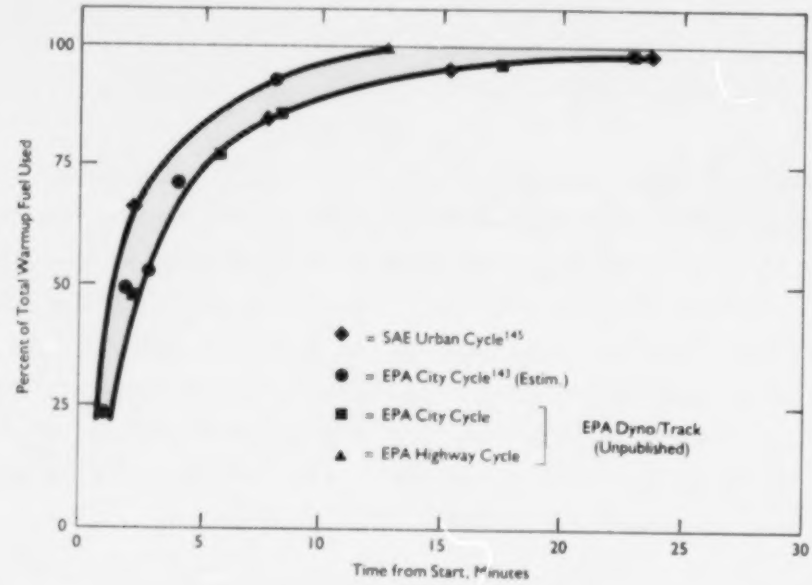
It is clear from all of these data that the excess fuel used for vehicle warmup is consumed in the early stages of cold-start driving. The table following lists the warmup fuel, i.e., that in excess of FWU fuel, for these tests.

Excess Fuel Consumed for Warmups

	Four SAE Urban Cycles	EPA City Cycle	EPA Highway Cycle
Average Excess fuel, % of FWU fuel:	(8 miles)	(7.5 miles)	(10.2 miles)
All cars, Track	15.4%	12.0%	10.6%
All cars, Dynamometer	---	10.5%	8.4%
Total Excess gallons:			
4-cylinder cars	.059	.039	.034
6-cylinder cars	.088	.056	.053
8-cylinder cars	.091	.082	.062

The rate at which this excess fuel is consumed is plotted in the next figure: within five minutes of start up, 75% of warmup fuel has been consumed; within 10 minutes, 90%.

FIGURE 45. Rate of Consumption of Warmup Fuel



Although vehicles achieve fully-warmed up MPG capability relatively soon after start up, the cumulative fuel economy of a cold start trip is affected throughout the trip by the initial usage of warmup fuel. A formula by Tobin and Horowitz[146] relating cumulative cold start and fully warm trip fuel consumptions is equivalent to:

$$\frac{\text{Cold Start Trip MPG}}{\text{Fully Warm MPG}} = \frac{1}{1 + T^{-0.8}} \qquad [70°\text{F}]$$

Where T = trip length, in miles.

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[146] Op. Cit. (82)

Using this formula, a trip length of 16 miles is required for cold start trip MPG to reach 90% of fully-warm MPG; 40 miles for 95%, 130 miles for 98%, and 312 miles for 99%.

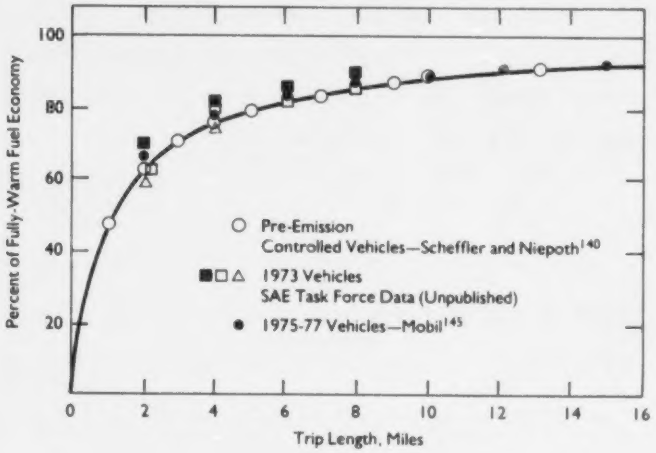
The triple figure illustrates how cumulative cold start trip fuel economy varies with vehicle vintage, ambient temperature, and car size. The top graph shows that cars built in the 1970's achieve relative warmup trip MPG's as high as, or higher than, cars built prior to 1968. There is no significant difference in relative warmup trip MPG between pre-and post-1975 models.

The middle graph shows the depression of cold start MPG which results from operation at low ambient temperatures. The solid curve is the Tobin and Horowitz formula, and the dashed curve from Scheffler and Niepoth[81], which data was the basis for the formula. The circles are from EPA analysis of late-model car data from Mobil Oil[85], and reveal a significantly greater temperature sensitivity for the later models (as was discussed earlier in this report). At temperatures in the 70's, the later models' relative warmup economy is quite like that of the older cars; however, the later models at 25°F achieve FWU fractions no better, and perhaps worse, than the older cars at 10°F.

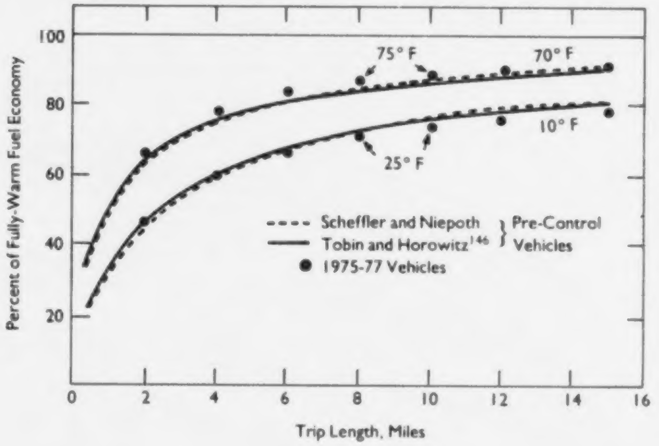
The bottom figure, also based on the Mobil data, shows that the warmup curves vary with car size. This does not indicate that smaller cars warm up more slowly than large ones, however, since the 75°F curves are nearly superimposed; the difference in the curves at lower temperatures reflects higher sensitivity to temperature for the small cars, also discussed earlier.

FIGURE 46. Cumulative (Trip) Fuel Economy

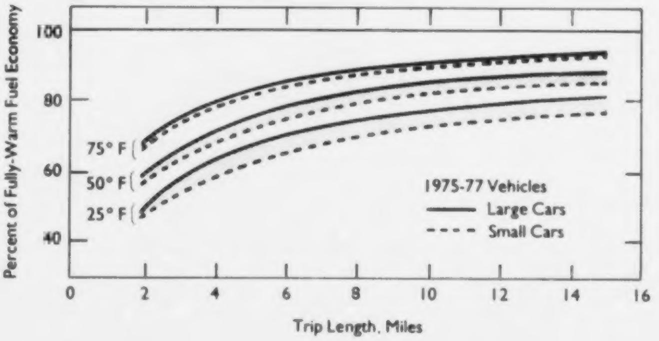
(a) Model year differences



(b) Temperature / model year differences

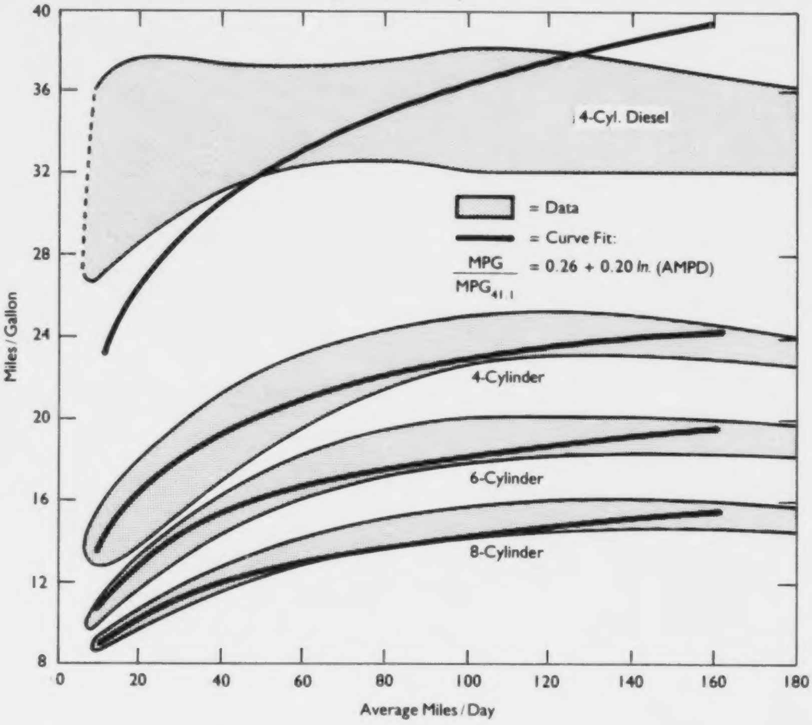


(c) Temperature / car size differences



d. Average Miles per Day: A Useful Parameter: More often then not, fuel economy surveys do not include detailed data on travel specifics such as average speed and trip length. An easily obtainable parameter, which does reflect the interaction of these characteristics, is average miles traveled per day (AMPD). Correlation between AMPD and fuel economy has been known for some time: the figure, from a 1964 study[147], shows the MPG influence of AMPD for a small sample of cars from model years 1958 - 1963.

FIGURE 47. Fuel Consumption vs. Miles Per Day in User Operation
(1958-63 Models)



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[147] Warren, "Some Factors Influencing Motorcar Fuel Consumption in Service", SAE paper, 1964.

For gasoline-powered cars, these data show that:

- Fuel economy increases with AMPD; the hint of an MPG downturn above 120 miles/day is believed to reflect high-speed driving penalties for long trips;

- Fuel economy for the same vehicle can vary over a range of nearly 2-to-1 in response to AMPD;

- At comparable AMPD, there is a clear distinction between vehicles' MPG capabilities as a function of engine (and vehicle) size; these distinctions can be masked by differential vehicle usage, however: four-cylinder small cars can be driven inefficiently enough to subchieve MPG levels lower than those of an efficiently-driven 8-cylinder large car;

- Fuel economy response to AMPD can be approximated by a logarithmic relation, shown by the heavy solid lines on the figure. The normalization point for this curve fit was selected at 41.1 miles/day (15,000 miles/year).

The data also show the Diesel car to be relatively insensitive to AMPD, not an unexpected result since Diesel engines are known to be highly efficient at part load and less so at high RPM. This finding is also in line with lower EPA Highway-to-City MPG ratios observed[148] for late-model Diesel Certification cars (1975-79 average ratio = 1.30) compared to gasoline engine cars (1975-79 average ratio = 1.40).

Analysis of GM customer survey data shows the AMPD response of 1975 model gasoline cars to be much the same as Warren's gasoline cars; the next figure shows data[149] for four GM 1975 model types. The apparent wider scatter in this recent data comes from the cars being driven in different regions of the U.S. and in different seasons of the year.

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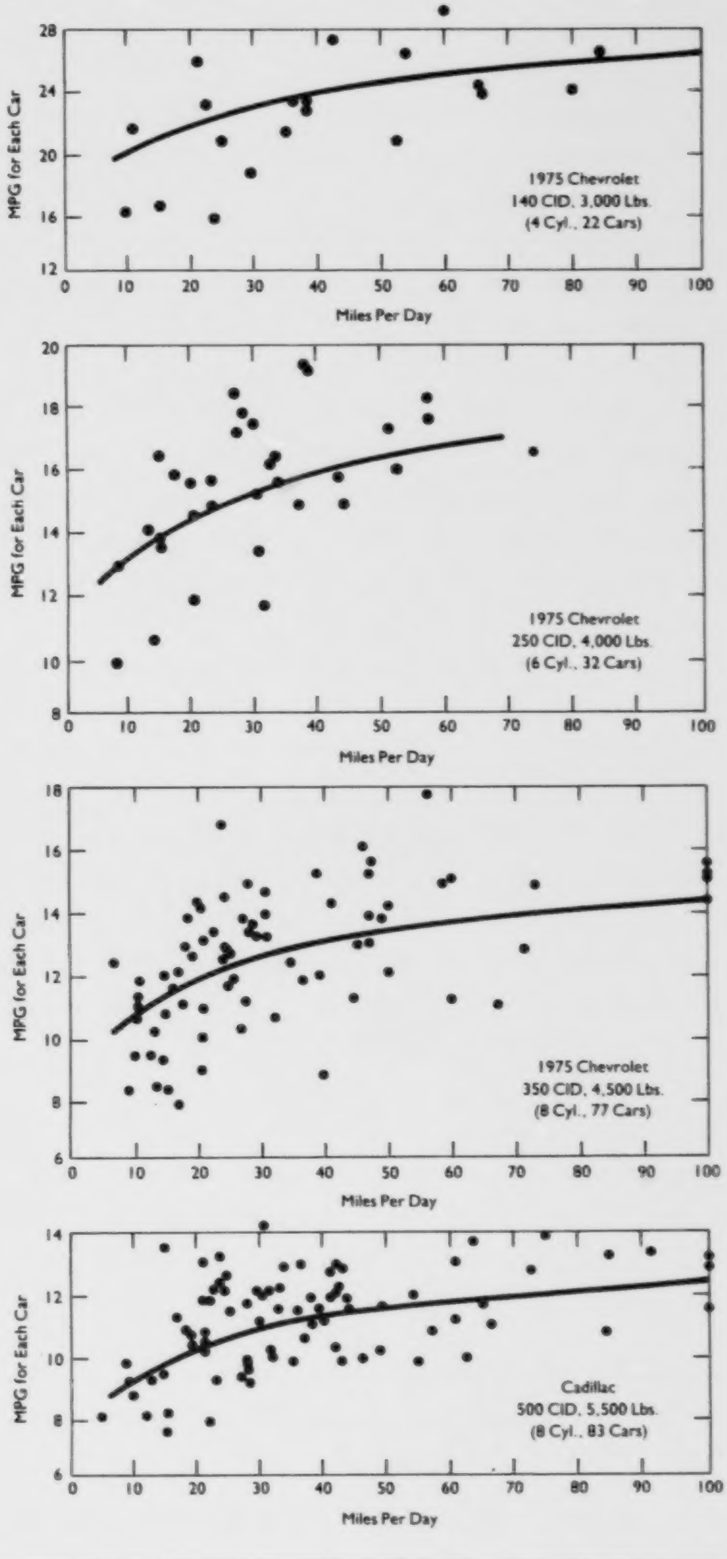
[148] Murrell, "Light Duty Automotive Fuel Economy ... Trends Through 1979", SAE paper 790225, February 1979.

[149] Janz, "Analysis of GM Fuel Economy Surveys", EPA Report EPA-460/3-76-029, October 1976.

FIGURE 48.
In-Use Fuel Economy
vs.
Average Miles Per Day

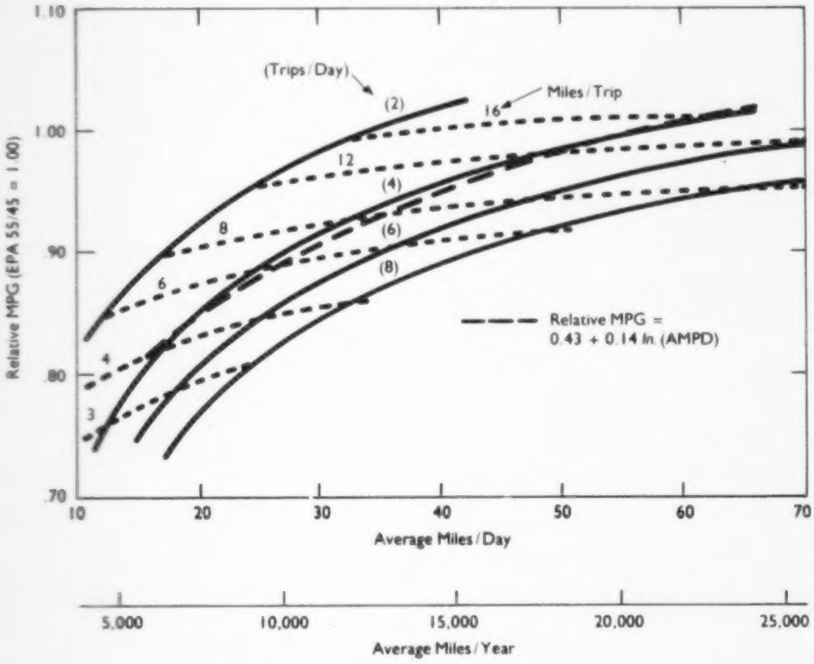


The curves superimposed on each of the four data sets are not separate curve fits for those models, but the curve fit for the entire survey data base,

$$\frac{MPG}{MPG_{41.1}} = 0.535 + 0.125\ ln(AMPD)$$

A travel characteristics analysis made for this report (see Appendix E) relates normalized MPG to trip frequency and length; when plotted against AMPD, the figure below is obtained. This model is more than just shapewise similar to the vehicle data: it is (at constant trip frequency) in excellent agreement with a logarithmic MPG:AMPD relationship, whose log term coefficient lies between those of the curve fit equations for the Warren and GM data.

FIGURE 49. Relationships Between Fuel Economy and Travel Characteristics
(From Appendix E)



As an illustration of the value of knowing the AMPD characteristics of cars in a data base, consider the following. Unpublished data furnished by Mobil Oil Co. on the road fuel economy of a number of 1975 and 1976 company cars, each driven by several employees over a period of weeks, was analyzed for in-use fuel economy influences. Ranking the cars in order of average MPG slip (road-to-EPA MPG ratio), the top 20% and bottom 20% were compared. The "best-slip cars" were mostly 1975 models, relatively large, all V-8 powered (average CID = 341), with average EPA MPG less than 15; the "worst-slip cars" were mostly 1976's, smaller, predominantly 4- and 6-cylinder (average CID = 188), with average EPA MPG above 20. Based on this alone, it could be concluded that higher shortfalls are characteristic of small, high-MPG cars, and/or there is a year-to-year growth in road shortfall.

When the usage patterns of these two groups of cars are compared, however, the following appears:

	"Best Slip" Cars	"Worst Slip" Cars
Average EPA MPG	13.8	23.3
All Possessions (up to 14 drivers each car)		
Average miles/day	37.6	28.3
Average road MPG	13.2	17.1
Average slip, R/E	0.96	0.74
Best-MPG Possessions (all cars)		
Average miles/day	50.8	35.9
Average road MPG	16.3	19.6
Average slip, R/E	1.18	0.85
Worst-MPG Possessions		
Average miles/day	30.0	9.9
Average road MPG	11.3	14.7
Average slip, R/E	0.82	0.63

The best-slip cars (notice we have labeled the cars) are the ones driven at higher AMPD's, and the worst-slip cars are the ones subjected to the least fuel efficient travel.

Relative success of the various drivers of the Mobil cars sheds yet more light on the effect of AMPD on fuel economy; ranking the drivers in order of MPG slip, and comparing the top 20% and bottom 20%, we find:

	"Best MPG" Drivers	"Worst MPG" Drivers
Average EPA MPG	16.1	17.2
Average miles/day	44.6	30.2
Average road MPG	14.9	13.4
Average slip, R/E	0.92	0.78

Although working with a group of vehicles with a 6% EPA MPG disadvantage, the "Best MPG" drivers achieved 11% higher MPG on the road -- by driving nearly 50% higher AMPD.

The "Best MPG" drivers, of course, are not necessarily the most fuel conservative. This is a good example of the pitfalls inherent in making value judgments such as "Best" or "Worst" on the basis of fuel economy. When fuel consumption is considered, the value judgements sometimes reverse as the following table indicates:

	"Best" (MPG Basis) Drivers	"Worst" (MPG Basis) Drivers
Miles Per Day	44.6	30.2
Miles Per Gallon	14.9	13.4
Gallons Consumed Per Day	3.0	2.3
Value Judgement, Based on Fuel Consumption	"Worst"	"Best"

This shows that emphasizing fuel economy (MPG) as a figure of merit can lead to conclusions opposite those based on use of fuel consumption as the figure of merit. One problem occurs, however, when attempting to evaluate fuel efficiency on a consumption basis: fuel consumption is not a measure that many people are familar with. While many people have an idea of how many "MPG's" they get with their car, we would predict that significantly fewer people know how many gallons per mile they consume. This discourages analysis or discussion in fuel consumption terms, even though reduced fuel consumption is probably a more appropriate measure, and higher fuel economy is only one approach toward reducing fuel consumption.

AMPD has been found to vary with population density and other factors, from the 1975 GM customer survey data (although the statistical significance of the observations is not good). The following table lists these findings. AMPD is notably lower for more densely-populated areas, and--for all population densities--AMPD is lower for the smaller cars. Similarly, MPG shortfalls are worse for higher population densities and for higher-MPG levels.

Dependence of AMPD on Population Density and Other Factors, MY 1975 GM Cars

	Population (Owner ZIP Code)			U.S. Average:	
	25,000	25,000-999,999	≥ 1 million	Sample-Weighted	VMT-Weighted
Percent of Cars in Sample	48.0	47.6	4.4		
Percent of VMT (NPTS#7)[150]	66.3	27.3	6.4		
Average miles/day	46.6	39.1	29.6	42.3	43.5
Standard Deviation of AMPD	61.3	41.2	18.0	--	--
Average slip, Road/EPA	.901	.855	.798	.874	.881
AMPD vs. Vehicle Weight:					
3000 lb	40.9	31.3	28.1	35.9	37.5
4000 lb	44.8	36.6	29.1	40.2	41.6
5000 lb	48.7	41.9	30.0	44.5	45.6
AMPD vs. Engine CID:					
150 cu. in	42.3	34.3	23.1	37.9	38.9
250 cu. in.	44.5	36.8	26.2	40.2	41.2
350 cu. in.	46.8	39.3	29.4	42.4	43.6
Road MPG:					
EPA = 10	9.2	8.6	8.0	8.9	9.0
15	13.3	12.5	11.7	12.8	13.0
20	17.2	16.2	15.2	16.6	16.8
27.5	22.5	21.2	20.3	21.8	22.0

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[150] Goley, *et al*, "Nationwide Personal Transportation Study, Household Travel in the United States, Report No. 7', DOT/FHwA, April 1972.

e. Acceleration Intensity: As mentioned earlier, once vehicle average speed is determined by all the factors that influence it, the only other factors that affect cyclic driving fuel economy are related to acceleration and deceleration intensity. These two factors are highly correlated[151], reflecting a sort of "aggressiveness index" which is common to speed changes in general, whether accelerating or decelerating. While decelerations are of critical interest for emissions, it is the accelerations in a driving cycle that impact most heavily on fuel consumption, and it is upon those that we will concentrate.

Two different aspects of acceleration level are of interest here. There is the matter of the usual quantitative engineering research, wherein acceleration rates and their MPG influences have both been carefully measured. Perhaps more striking, however, are reports of the significant effect on fuel economy of driver acceleration habits and modification of those habits.

(1) Quantitative Studies - Scheffler and Niepoth[81] reported in 1965 that halving the 4.1 mph/sec acceleration rates of a city driving cycle improved MPG by 7.7%, while doubling the base rates caused a 5.8% loss.

More recently, EPA has conducted and sponsored tests and computer simulations of the fuel economy effects of altered speed change rates in the EPA test cycles.

The test projects involved modified versions of the EPA Highway cycle, wherein acceleration and deceleration rates were either increased by some 50% (an "increased-noise" modification) or completely eliminated (a "smoothed" modification, with a constant cruise at 50 mph between the cycle's initial acceleration and final deceleration). The next figure shows the standard Highway cycle speed vs. time schedule and an example of a noise-accentuated version of the cycle.

The results of the tests are summarized in the table following. All of the test cars were 1976 models.

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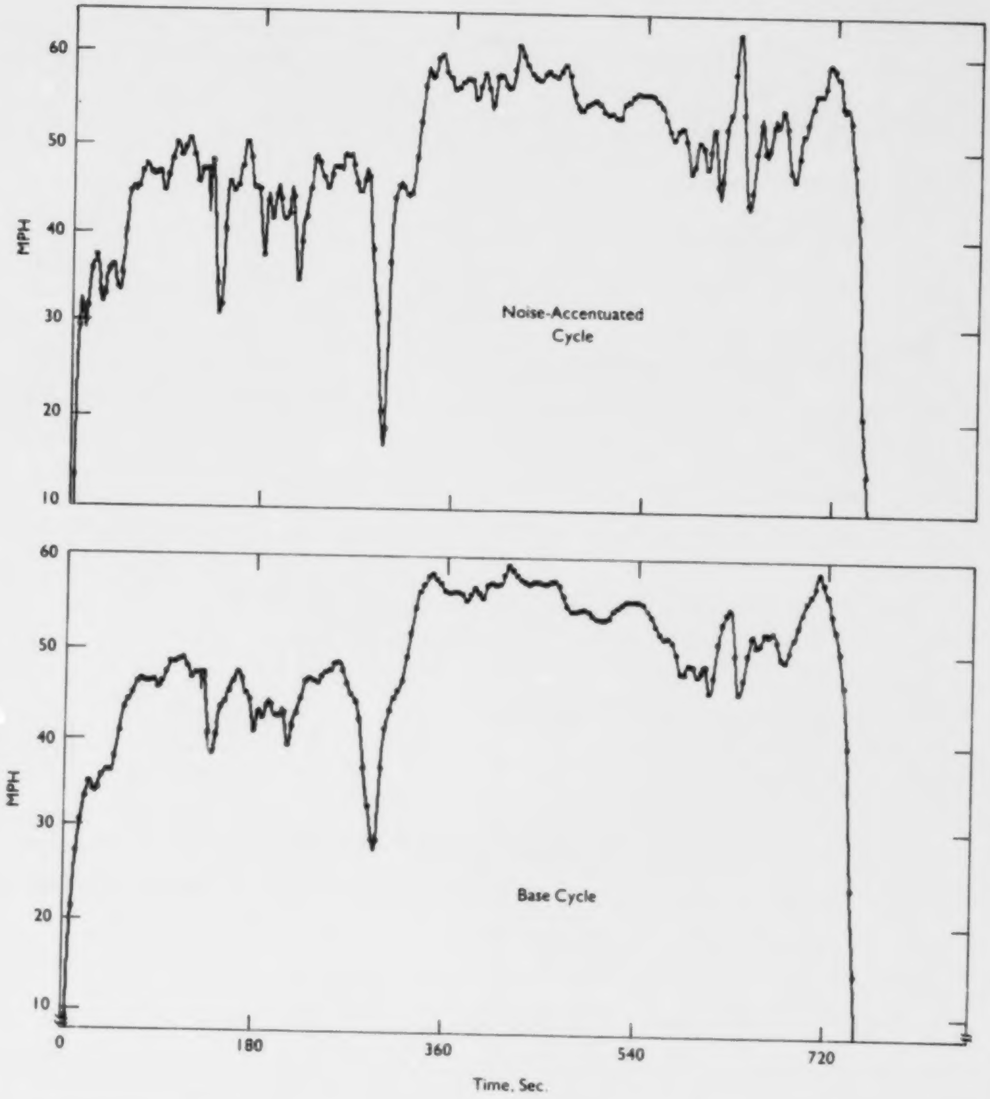
[151] Evans, et al, Op. Cit. (132)

FIGURE 50. Example of Driving Cycle Modification in EPA Dyno/Track Project



Effect of Modified Acceleration/Deceleration Rates on EPA Highway Cycle Fuel Economy: Test Data

	Standard Cycle	"Noisy" Cycle	"Smooth" Cycle
Average Speed, mph	48.2	48.6	48.3
Average Speed Change Rates, mph/sec[a]			
- Acceleration	0.33	0.48	Zero
- Deceleration	-0.34	-0.48	Zero
Fuel Economy Effect			
SwRI, 3 cars, dynamometer[b]		-4.3%	+4.4%
EPA, 6 cars, dynamometer[c]		-3.0%	+4.5%
EPA, CVCC, dynamometer		-0.5%	+2.0%
EPA, 6 cars, test track		-4.4%	+6.5%

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[a] Excluding initial acceleration and final deceleration

[b] Reference 122.

[c] Dynamometer vs. Track Project, Phase II (unpublished)

Fuel economy sensitivity to accelerations did not vary with vehicle size in either of these test projects, for those cars using conventional engines. In the EPA dynamometer tests, the CVCC stratified charge car showed noticeably less acceleration sensitivity than the other cars. In the SwRI tests, the application of significant (∿ 30%) increases in inertia weight and road load horsepower resulted in only slight reductions in fuel economy sensitivity to acceleration rate.

In the computer simulation projects accentuated-noise versions of three driving cycles (New York City, EPA City and EPA Highway) were employed. Model year effects were also investigated, and two completely different simulation programs were used. Although the simulations were computer models, all key inputs came from test data from real vehicles or engines. The results are shown in the next table.

Effect of Modified Acceleration/Deceleration Rates on Cyclic Driving Fuel Economy: Computer Studies

	NYC Cycle	EPA City Cycle	EPA Highway Cycle
Average Speed, mph			
Base Cycles	7.5	19.6	48.2
"1.5x" perturbed cycle	9.4	21.0	48.3
"2.0x" perturbed cycle	13.9	22.9	48.4
Average Acceleration rate, mph/sec			
Base Cycles	1.38	1.13	0.44
"1.5x" perturbed cycle	2.97	1.73	0.65
"2.0x" perturbed cycle	4.69	2.65	0.96
Average Deceleration rate, mph/sec			
Base Cycles	-1.36	-1.29	-0.50
"1.5x" perturbed cycle	-2.96	-1.92	-0.72
"2.0x" perturbed cycle	-4.75	-2.72	-1.14

Fuel Economy Effect:	NYC Cycle		EPA City Cycle		EPA Highway Cycle	
	1.5x	2.0x	1.5x	2.0x	1.5x	2.0x
1973-74 Models[a]	-24.3%	-49.3%	-16.0%	-36.5%	-7.5%	-16.0%
1975 Models[a]	-34.5%	-62.2%	-20.7%	-44.4%	-5.9%	-16.1%
1975-77 Models[b]	-19.9%	-27.1%	-16.8%	-34.8%	-6.6%	-15.6%
1975 CVCC[b]	-7.0%	+4.2%	-8.2%	-17.0%	-4.1%	-10.2%

[a] Modal Analysis Simulations, Ref. 135; 180 1973-74 cars, 225 1975 cars

[b] Modified DOT VEHSIM Simulations, Ref. 152; three cars

For the two lower-speed cycles, the 1975 models appear more highly MPG-sensitive to acceleration than the 1973-74 models. The stratified charge car (as was observed in the EPA tests) shows significantly less acceleration sensitivity than those with conventional powerplants.

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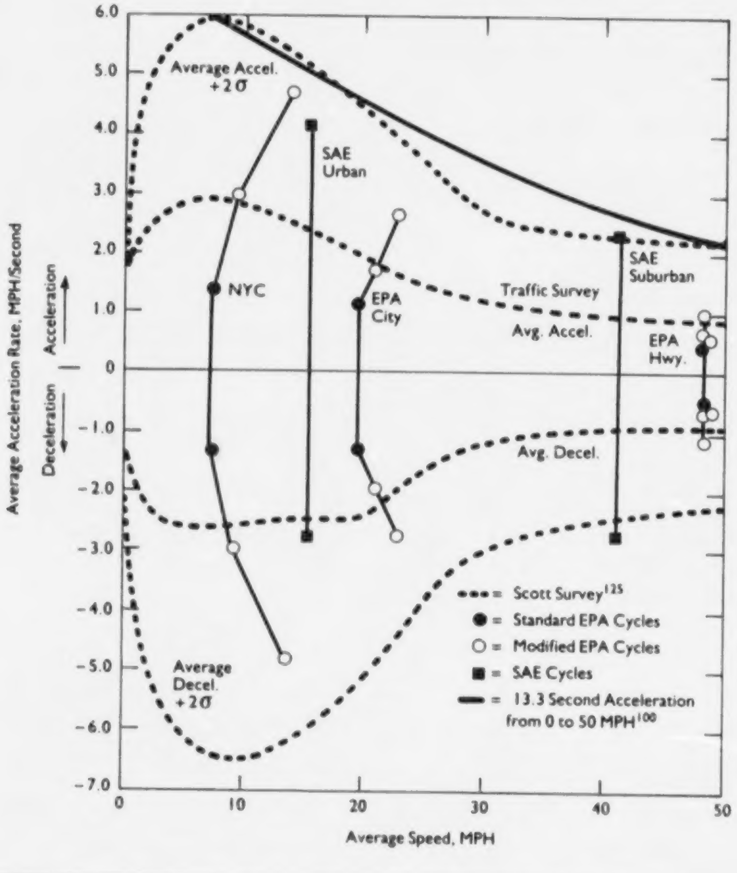
[152] Thacker and Smalley, "Emission Modeling and Sensitivity Study", EPA Report EPA 460/3-79-005, May 1979.

The average acceleration and deceleration rates for the various EPA cycles, and also the SAE road test cycles, are compared with traffic survey data[153] in the next figure. The average rates for the NYC and EPA cycles are roughly half those of the survey data, while average rates for the SAE cycles and the "most-perturbed" EPA urban cycles are at least 1σ above the survey average rates. For perspective, the "+2σ" acceleration level corresponds closely to the envelope of a wide-open throttle acceleration from zero to 50 mph in 13 seconds.

FIGURE 51. Comparison: Average Acceleration Rates (Time-Weighted): EPA Cycles, SAE Cycles, and Traffic Survey Data



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[153] Scott Research Laboratories, Op. Cit. (125)

It can be misleading to compare only the average speed change rates of these cycles, because large differences exist among the cycles as to proportion of time spent accelerating. A more consistent measure of cycle acceleration intensity effects is the integral:

$$\int a\cdot v\cdot dt_a$$

where "a" is instantaneous acceleration rate, "v" is instantaneous speed, and "dt_a" represents each time increment spent accelerating. The cycles can be compared on the basis of this integral, or its approximation:

$$\bar{a}\cdot\bar{v}\cdot t_a/t_t$$

where $\bar{a}$ and $\bar{v}$ are cycle average values and t_a/t_t is fraction of cycle time spent accelerating[154]. The resultant parameter has the units of power per unit mass; for familiarity it is expressed as horsepower for a 3500-lb vehicle, in the following table:

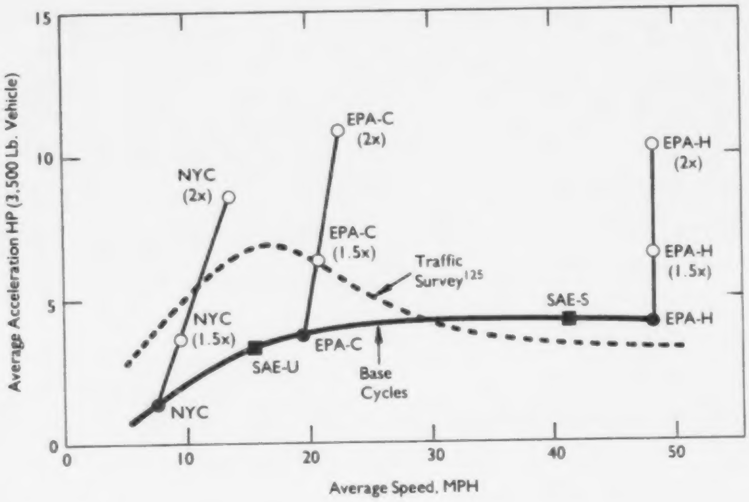
Cycle		$\bar{a}$	$\bar{v}$	t_a/t_t	HP_{3500}
NYC,	base	1.38	7.5	0.30	1.32
	1.5x	2.97	9.4	0.30	3.56
	2x	4.69	13.9	0.31	8.59
SAE Urban		4.17	15.6	0.12	3.32
EPA City,	base	1.13	19.6	0.40	3.77
	1.5x	1.73	21.0	0.41	6.33
	2x	2.65	22.9	0.42	10.83
SAE Suburban		2.33	41.1	0.10	4.07
EPA Hwy,	base	0.44	48.2	0.44	3.97
	1.5x	0.65	48.3	0.48	6.41
	2x	0.96	48.4	0.51	10.07
Survey		1.78	26.0	0.29	5.70

---

[154] Use of the time fraction normalizes all the data, since total time values range from minutes for the test cycles to hundreds of hours for the survey data.

These data are shown in the following figure, with the average acceleration power for the traffic survey[153] distributed over the speed range. The fact that the base cycles' average power requirements lie on the same smooth curve explains in part why fuel economy results (shown earlier) from these base cycles also lie on a smooth curve.

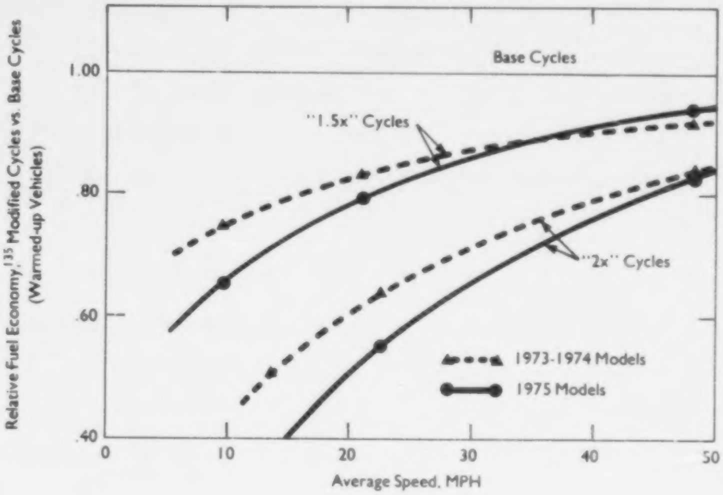
FIGURE 52. Comparison: Test Cycles' Average Acceleration Power vs. Traffic Survey Data



It is clear that actual traffic, at low average speeds, involves significantly higher acceleration power loadings than the base versions of the EPA and SAE test cycles. The next figure illustrates the fuel economy penalties associated with the harsher acceleration modified test cycles.

Fuel being wasted by higher acceleration driving can be saved through more conservative driving habits, as discussed in the next section.

FIGURE 53. Fuel Economy Penalties for Acceleration in Excess of EPA & SAE Test Cycles



(2) Driver-habit Studies - The Southern California Auto Club[155] measured fuel economy effects of subjectively-selected ("easy", "moderate", and "heavy") acceleration styles. A total of twenty 1969-73 cars were tested, including six weighing less than 3000 lb., eight between 3000 and 4000, and six over 4000 lb. The tests were run on an auto raceway, and consisted of 0-40 mph accelerations, followed by 40 mph cruises, for a total distance of 1/4 mile. Duplicate runs were made at each acceleration intensity. The results are as follows:

Effect of Acceleration Level
on Fuel Economy

	Small Cars	Medium Cars	Large Cars
"Easy" Acceleration	+7.8%	+12.5%	+16.1%
"Moderate"	..........Base Case..........		
"Heavy"	-15.3%	-11.1%	-9.4%

This would suggest that smaller cars have less to gain and more to lose as acceleration intensity is varied, but since actual rates were not measured, it is not known whether the tests really imposed similar rates on all the cars.

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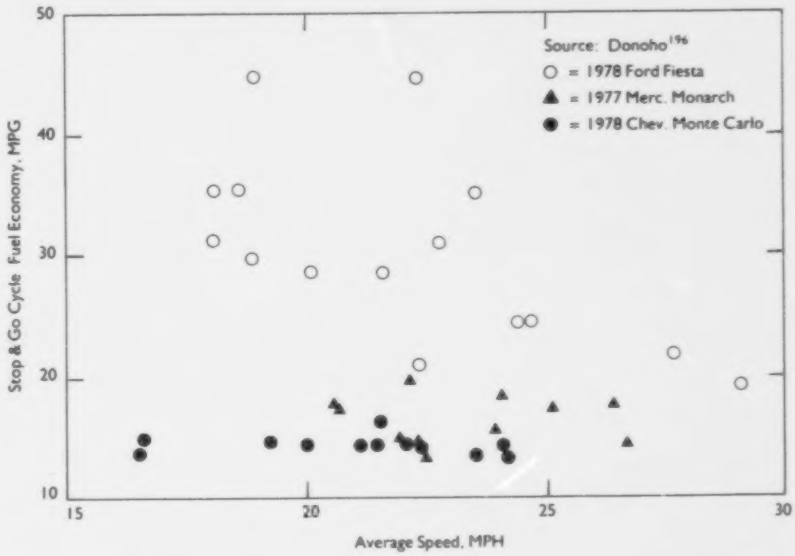
[155] Bintz and Banowetz. "Fuel Economy Testing", Automobile Club of Southern California Report, September 1973.

A more recent study[156], jointly sponsored by the SAE and California State University at Chico, similarly evaluated the effect of subjective acceleration variations on fuel economy. Three late-model cars were driven by 11 to 15 drivers each, over a four-mile course having 13 stops plus 14 right-angle turns. The results are shown in the figure, with MPG plotted against average speed. Since the test course and its stop and slowdown constraints were fixed, the higher average speeds correspond to harder-acceleration driving.

FIGURE 54. Fuel Economy Under Variable Acceleration Conditions



Source: Donoho[156]

As discussed earlier, fuel economy improves with higher average traffic flow speeds (up to some 40 mph) when normal accelerations are used. The Chico State data show that this potential MPG improvement is, at best, nullified when the average speed increase is brought about by hard accelerations. In the case of the smaller 4-cylinder car, the result of acceleration-related speed increases caused significant fuel economy losses.

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[156] Donoho, "EPA MPG -- How Realistic?" SAE paper 780366, December 1977.

Claffey[157] conducted tests over a 3.5-mile course with 14 stops and 19 turns, using one 1968 car and 55 drivers. The drivers were divided into four groups:

(a) 26 males, ages 16 to 70, who each drove the course once, using "normal" driving techniques (unprompted), then repeated the drive using a dash-mounted vacuum gauge to promote reductions in acceleration rates;

(b) 20 females, ages 16 to 80, who each drove the course twice as did group (a);

(c) 8 drivers (5 female, 3 male), ages 30 to 60, who each drove the course twice: acceleration reductions in this group's repeat drives were accomplished without vacuum gauge assistance; this group initially (when driving normally) had a lower average MPG than groups (a) and (b);

(d) One driver (male, age 53) who made multiple trips driving normally, then more multiple trips at two progressive levels of fuel conservation technique (without gauge assistance); in the first (unprompted) round, this driver's average MPG was lower than any of the averages for groups (a), (b) and (c).

In the "normal driving" trips, acceleration rates up to 6.2 mph /sec and deceleration rates to -9.6 mph/sec were observed. Manifold vacuum readings below 10 in. Hg (indicating hard acceleration) occurred for 35% of the drivers (19 out of 55). Overall average "normal driving" speed was 21.4 mph. In the gauge-assisted repeat trips for groups (a) and (b), manifold vacuums were kept from going below 10 in. Hg.

In the gauge-unassisted repeat trips ("full fuel conservation" driving) for groups (c) and (d), acceleration and deceleration rates were limited to +3.5 mph/sec and -4.5 mph/sec respectively. Overall average speed for these conditions was 18.1 mph.

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[157] Op. Cit. (114)

For groups (a) and (b), the effect of vacuum gauge assistance depended upon whether "normal" driving was harsh or conservative. For those who were already conservative drivers (58% of the males and 80% of the females). gauge-assisted driving produced mixed results, ranging from small MPG improvements to small MPG degradation: for some of these drivers, the gauge was more of a distraction than an aid. For all of the initially hard-accelerating drivers (42% of the males and 20% of the females), MPG was improved by gauge-assisted acceleration reduction. The results are summarized in the next table.

Fuel Economy Effect of Limiting Accelerations with Vacuum Gauge Assistance

	Group (a) 26 Males	Group (b) 20 Females
A. "Easy" Drivers: Those with no low vacuums when driving normally		
1. Those whose MPG improved with gauge assistance		
Number	5	5
MPG, normal driving	10.47	10.60
MPG, limited acceleration	10.54	10.76
Change in MPG	+0.7%	+1.5%
2. Those whose MPG did not change with gauge assistance		
Number	3	3
MPG, normal driving	10.25	10.38
MPG, limited acceleration	10.25	10.38
3. Those whose MPG worsened with gauge assistance		
Number	7	8
MPG, normal driving	10.59	10.63
MPG, limited acceleration	10.33	10.33
Change in MPG	-2.5%	-2.8%
Total effect for all "easy" drivers combined:		
Number	15 (58% of males)	16 (80% of females)
MPG, normal driving	10.48	10.57
MPG, limited acceleration	10.38	10.47
Change in MPG	-1.0%	-0.9%

Fuel Economy Effect of Limiting Accelerations with Vacuum Gauge Assistance (Cont'd)

	Group (a) 26 Males	Group (b) 20 Females
B. "Hard" Drivers: Those with low vacuums when driving normally		
Number	11 (42% of males)	4 (20% of females)
MPG, normal (for them) driving	9.87	10.02
MPG, limited acceleration	10.25	10.52
Change in MPG	+3.9%	+5.0%

For group (c), all of the initially "hard" drivers, and four of the five initially "easy" drivers, achieved improved fuel economy by acceleration reductions without gauge assistance, as shown in the next table.

Fuel Economy Effect of Limiting Accelerations without Vacuum Gauge Assistance, Group(c)

	Males	Females
A. "Easy" Drivers:		
Number	2	3[a]
MPG, normal driving	10.46	9.93
MPG, limited acceleration	10.82	10.52
Change in MPG	+3.4%	+5.9%
B. "Hard" Drivers:		
Number	1	2
MPG, normal driving	8.88	9.90
MPG, limited acceleration	9.29	10.49
Change in MPG	+4.6%	+6.0%

---

[a] Two improved (+18.4% and +6.4%); one worsened (-6.0%)

The test results for the last driver, "group" (d), again confirmed the fuel economy improvement potential of conservative speed change rates, and also yielded data on fuel economy repeatability, given in the following table:

Fuel Economy Effects of Limiting Accelerations,
Driver (d)

	Normal Driving	Partial Fuel Conservation	Full Fuel Conservation
Number of trips	15	20	11
Fuel Economy, MPG:			
Average	9.84	10.02	10.50
Range	9.51-10.28	9.78-10.33	10.28-10.76
C.O.V.	2.17%	1.70%	1.26%

With progressive attention to minimizing acceleration and deceleration rates, this driver improved his average fuel economy by 6.7% and improved in consistency as well. Under the conditions most highly conducive to repeatability (same driver, same car, same route, controlled driving technique), there remained a 1% coefficient of variation, and a range of 0.5 MPG. This residual variability includes the driver's trip-to-trip variability, the car's test-to-test variability, and the variability of the fuel measurement hardware.

A driving-technique experiment was reported by Evans[158] for 34 trips made by nine different drivers over a fixed 16.8-mile route in suburban Detroit. All trips used the same 1974 vehicle, and the drivers were given various driving instructions. The driving techniques used were in response to these qualitative instructions. Two instructions involved the use of a vacuum gauge "fuel economy meter" with a three-color dial: a green (high vacuum) region intended to indicate good fuel economy, and orange and red regions indicating lower vacuums, higher power, and reduced fuel economy. The instructions used were:

1. *"Drive normally with the traffic";*
2. *"Minimize trip time";*
3. *"Use vigorous acceleration and deceleration";*
4. *"Minimize fuel consumption";*
5. *"Maintain fuel economy meter in green region";*
6. *"Maintain fuel economy meter in green or orange region";*
7. *"Drive like a hypothetical very cautious driver".*

---

[158] Evans, "Driver Behavior Effects on Fuel Consumption in Urban Traffic", General Motors Research Report GMR-2769, June 1978.

In response to instruction 4, the drivers divided into two subgroups which interpreted the instruction differently. One group responded by reducing accelerations and speeds, while the other group attempted to minimize stops at traffic signals, even occasionally accelerating to "make a light".

In response to instruction 5, it was found impractical to keep the meter in the green zone only; the required acceleration rates were unrealistically low with respect to the prevailing traffic. Allowing some orange-zone meter readings (instruction 6) permitted more realistic driving, while still imposing some limits on acceleration rates.

The results of the experiment are given in the table, with the instructions (and sub-interpretations of instruction 4) listed in order of decreasing fuel economy.

Effect of Driving Technique on Fuel Economy and Trip Speed

	Fuel Economy, MPG		Average Speed, mph		Trip Time, min.	
Driving Technique	Avg.	Change	Avg.	Change	Avg.	Change
4b. Minimize stops	13.52	+16.1%	25.93	+3.3%	38.8	gain 1
7. Drive very cautiously	12.51	+7.4%	23.31	-7.2%	43.2	lose 3
4a. Reduce accels. and speeds	12.44	+6.8%	24.06	-4.2%	41.8	lose 2
6. Keep meter in green/orange	12.31	+5.7%	24.75	-1.4%	40.7	lose 1
1. Drive normally	11.64	(base)	25.11	(base)	40.1	(base)
5. Keep meter in green	11.42	-2.0%	18.96	-24.5%	53.1	lose 13
2. Minimize trip time	10.59	-9.0%	29.06	+15.7%	34.6	gain 6
3. Use vigorous acceleration	9.92	-14.%	28.11	+11.9%	35.8	gain 4

With two notable exceptions, those instructions which increased average speed decreased fuel economy, and those which decreased speed increased fuel economy. In the highest-MPG case, "playing the lights", both average speed and fuel economy increased, in consonance with earlier observations that less stops (and corresponding higher average speeds) are good for fuel economy. In the case of instruction 5, average speed slowed, but fuel economy also decreased. Possible causes may include failure to achieve fuel-efficient cruise speeds, and aerodynamic disturbance from the traffic passing the test car.

(3) Effectiveness of Fuel Economy Meters - The evaluation of devices such as fuel economy meters is not within the purposes of this report; however, it is clear from the preceding section that instantaneous reading MPG meters are of questionable value in improving vehicle fuel economy. It is pertinent here to quote conclusions from three sources *vis-a-vis* instantaneous meters:

[From Claffey[114]]:

> ° "Nearly 70 percent of all drivers customarily drive without opening the throttle plate excessively anyway (maintain engine vacuum above 10 inches of mercury). These drivers would not be helped to save fuel by a vacuum gauge.
>
> ° Fifty percent of these drivers would actually consume more fuel if they were distracted in their driving by trying to adjust their driving habits to a vacuum gauge. This is especially true of women and older persons.
>
> ° Another 30 percent of all drivers, those who customarily jab the throttle pedal on accelerations, could benefit from a vacuum gauge as it would alert them to their fuel-wasting driving habits.
>
> ° The gauge distracts driver's attention and is unsafe. During test operations, there were, in 225 vehicle-miles of travel, three near-miss accidents directly caused by the driver's attention being distracted by the vacuum gauge.
>
> On the whole, a vacuum gauge mounted on the dashboard of all cars would not only have a negative effect on overall fuel conservation but would also increase the danger of highway accidents. It is not recommended."

[From Evans[158]]:

> "Banowetz and Bintz (1977) [our Ref. 159] compared the fuel economies of 70 vehicles equipped with fuel economy meters to those of 70 control vehicles not so equipped. The fuel economy meter displayed the (essentially) instantaneous miles per gallon. The drivers of all 140 vehicles were motivated to save fuel. The vehicles were used for 12 weeks of normal driving. The meter-equipped vehicles had fuel consumption, on average, 3% less than the non-equipped vehicles, though the authors report that they did not find this difference to be statistically significant."

[From DOT, in a report[160] to the Congress and the President, commissioned by the Energy Policy and Conservation Act, Section 512(a)]:

- This study did not establish that use of mpg meters in new cars would save enough fuel to measurably reduce the nation's fuel consumption and/or to offset their own cost within a reasonable period of time, where the reasonable period for cost offset was taken to be 3 years (i.e., first ownership).
- It has not been established that use of mpg meters will save significant amounts of fuel in average vehicles driven over average operating conditions. Moreover, mpg meters have little potential for promoting fuel savings under congested traffic conditions.
- It would require about three years for a new large car or about six years for a new small car to pay for a factory installed meter if a 5% fuel economy increase could be obtained. For the least expensive commercially available mpg meters, costing about $130 installed in a used car, fuel economy increases of about 12% would be needed to cover the installed cost of the mpg meter within three years. These percentage increases in fuel economy are hypothetical examples.
- Means for encouraging consumers to purchase automobiles equipped with mpg meters include advertising, driver education, tax benefits, and subsidies to manufacturers of meters. These measures are only likely to be effective when it is shown that mpg meters are effective, economical, convenient and safe to use.
- There should be no requirement to install mpg meters in new cars.
- The Federal government should take no action to promote the installation and use of mpg meters in used cars at this time.

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[159] Banowetz and Bintz, "Field Evaluation of Miles-Per-Gallon Meters", DOT Report DOT-TSC-OST-77-64, November 1977.

[160] U.S. Department of Transportation, "Effectiveness of Miles-Per-Gallon-Meters as a Means to Conserve Gasoline in Automobiles", July 1976.

We emphasize that these conclusions apply to instantaneous-reading devices. Other types of "fuel economy meters" which give cumulative readings, rather than instantaneous readings, are in use; these other types may or may not share the disadvantages of the instantaneous-reading types.

f. Summary - Travel Characteristics Effects: The various aspects of vehicle travel are closely interrelated, and cannot be treated separately. Appendix E contains the analysis leading to our estimates of travel characteristics of new cars of recent model years, i.e., the type of vehicles addressed by this report.

Compared to EPA 55/45 conditions, that analysis shows that such vehicles travel longer average trip distances, at higher average speeds, with higher average acceleration rates, and a higher fraction of trips beginning with a cold engine, as summarized below:

Comparison of Estimated Travel Characteristics
to EPA 55/45 Conditions

	EPA 55/45	Estimated Actual	Actual MPG vs. EPA
Average trip length, miles	8.5	9.7	0.8% Higher
Fraction of trips started cold	26.9%	35.9%	0.7% Lower
Average trip speed, mph	26.7	32.7	10.5% Higher
Average acceleration HP (3500 lb car)	3.6	3.9	11.8% Lower

Thus, while specific travel details, on average, appear to be different from the EPA tests, the overall fuel economy shortfall that can be associated with travel characteristics in the aggregate is, due to the opposing effects, less than might be expected.

The detailed analysis, which considers regional, seasonal, urban vs. rural, and car size effects on vehicle travel, indicates small net shortfalls relative to EPA 55/45 conditions, as given in the next table.

Relative Fuel Economy Associated with Travel Characteristics Effects
(EPA 55/45 MPG = 1.000)

	Total U.S. (VMT-weighted)	
	Small Cars	Large Cars
Spring	0.951	0.977
Summer	0.980	1.004
Fall	0.957	0.982
Winter	0.941	0.968
Annual	0.958 (Shortfall = 4.2%)	0.983 (Shortfall = 1.7%)

The seasonal and car-size differences in relative MPG seen in the table above are due solely to differential vehicle travel patterns; the nominal 4% Summer-to-Winter MPG loss, for example, reflects only vehicle usage, not Winter losses related to temperature or road conditions.

FUEL ECONOMY INFLUENCES (Cont'd.)

Road Slip (Cont'd.)

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3. Vehicle Condition (Road)

This section considers fuel economy influences whose MPG effects are seen primarily, or exclusively, on the road.

a. Wheel Condition - The mechanical condition of the vehicle wheels can affect fuel economy through excessive brake drag and wheel misalignment.

Normal levels of drag in disk brakes are sufficient to cause fuel economy losses up to about 2.5%; improved brake system designs can eliminate more than half of this loss[161]. Additional data on abnormal disk brake drag, drum brake systems, and parking brake effects, and on the in-use distributions of these factors, would be required to evaluate precisely the magnitude of the in-use shortfall due to excessive brake drag, but we believe a figure on the order of 0.5% to 1% to be a conservative estimate.

Wheel alignment can have very significant MPG effects. Yurko[162] reports increases in tire rolling resistance of up to 25% per degree of slip angle, for tests of wheels not connected to a vehicle front-end suspension system. In vehicle tests at approximately 50 mph, the same report indicates rolling resistance increases up to 75% for front-wheel misalignments exceeding manufacturer's recommended maximum toe-out by 1/2 inch, and up to 23% for a 1/2 inch excessive toe-in. The Motor Vehicle Manufacturers Association[163] reports an 0.3 MPG fuel economy loss for 1/4 inch improper front wheel toe-in alignment; the operating condition and base level MPG are not specified. Unpublished data submitted to EPA by Honda Motors reports fuel economy penalties on the EPA City and Highway cycles of 3% and 2% respectively for front-wheel misalignments of 2 millimeters, and even measurable effects (1% MPG loss on the Highway cycle) of unbalanced tightening of wheel lug nuts.

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[161] Porter, "Design for Fuel Economy - The New GM Front Drive Cars", SAE paper 790721, June 1979.

[162] Yurko, "The effect of Wheel Alignment on Rolling Resistance - A Literature Search and Analysis", Report 78-12, Standards Development and Support Branch, ECTD, EPA, July 1978.

[163] Motor Vehicle Manufacturers Association, "Automobile Fuel Economy", September 1973.

Reference 162 points out from a DOT survey of 125,000 vehicles in five states that 19% of cars fail front-end alignment inspections, and concludes that perhaps 10% of all in-use vehicles are operating with a 4% MPG penalty due to front-wheel misalignment. This would correspond to a fleetwide MPG shortfall of 0.4% relative to the EPA tests.

b. Tire Size - One tire effect which shows up in both dynamometer tests and on the road is the effect of tire size. Since tires of different sizes have different rolling radii, a tire size switch affects the vehicle's N/V ratio[164]. A study of the rolling radii of various size tires in the 1977 Certification fleet gives the following N/V changes for various changes in tire size:

Average Change in N/V Ratio:

Tire Size Change	N/V Change
One-letter shift in tire size (e.g. CR78-14 to DR78-14)	-1.9%
One-inch shift in wheel size (e.g. F78-14 to F78-15)	-2.6%
Both of the preceding (e.g. FR78-14 to GR78-15)	-4.6%
Bias-belt to Radial type (e.g. B78-13 to BR78-13)	+1.2%
Bias to Radial + 1 letter (e.g. C78-14 to DR78-14)	-0.7%
Bias to Radial + 1 inch (e.g. H78-14 to HR78-15)	-0.9%
Bias to Radial + both (e.g. F78-14 to GR78-15)	-3.0%

Using average N/V sensitivity factors from Section IV.A.3. and the N/V changes which accompany tire size shifts, and assuming a 4% advantage for radial tires over bias-belted tires, the 55/45 fuel economy effects of the tire size changes are as shown in the next figure. Only changes which improve MPG are shown; of course, tire size changes against the direction of the arrows will decrease fuel economy.

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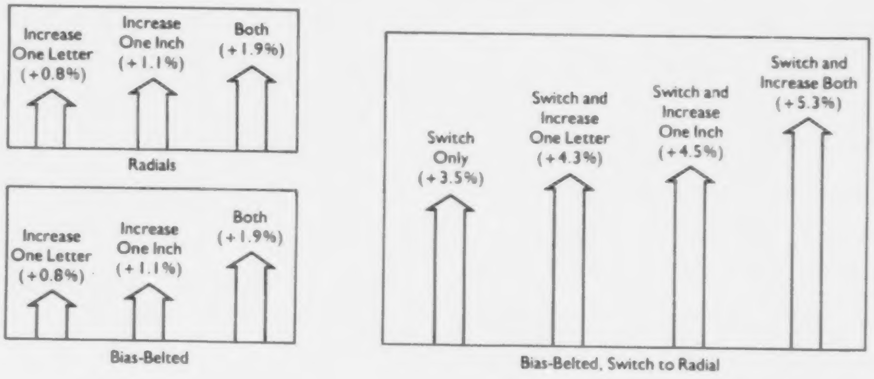
[164] See Section IV.A.3.

FIGURE 55. Typical Fuel Economy Effects of Tire Size Changes*



*If tire make is switched, MPG change can be higher or lower.

These calculated effects may be conservative estimates of the influence of tire size on fuel economy. In a study[165] of over 30 types and sizes of tires, the measured effects of wheel size changes over part of the EPA City cycle were as follows:

Measured MPG Effect of Change
from 14" Wheels to 15" Wheels, First
505 Seconds of EPA City Test

	Radial Tires	Bias-Belted Tires
Cold Start	+3.7%	+3.7%
Hot Start	+3.6%	+4.7%

Consumers have the option of making significantly fuel-efficient tire size changes, within mechanical limits such as wheel well clearance.

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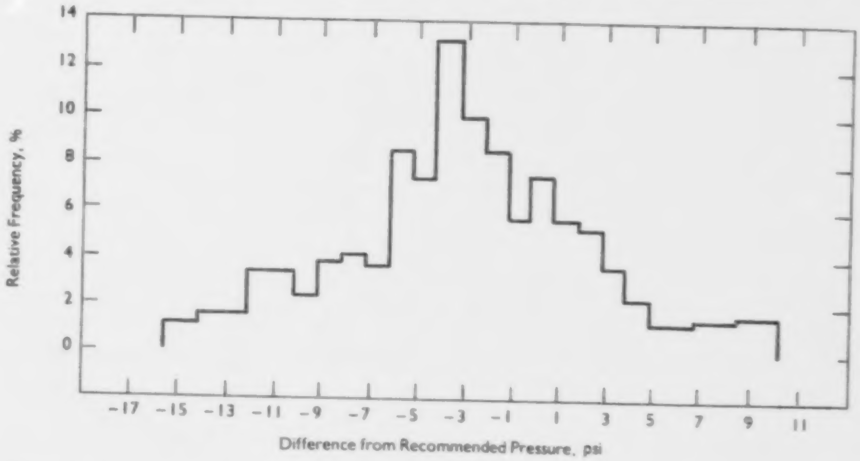
[165] Torres and Burgeson, "Comparison of Hot to Cold Tire Fuel Economy", Report 78-16, Standards Development and Support Branch, ECTD, EPA, December 1978.

c. Tire Pressure - This tire effect is exclusively a road slip item, since fixed, uniform tire pressures are used in dynamometer testing. An extensive survey[166] of the cold inflation pressures of nearly 9000 in-use tires reveals widespread underinflation, as much as 15 psi below manufacturers' recommendations. The figure shows a typical pressure distribution.

FIGURE 56. Example of In-Use Tire Pressure Distribution



Unpublished data from employee parking lot tire pressure surveys by B.F. Goodrich and Uniroyal show much the same results.

The MPG effects of tire pressure can be estimated using a tire energy sensitivity of -2.8% per psi[167] and MPG sensitivity to tire energy of

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[166] Viergutz, et al, "Automobile In-Use Tire Inflation Survey", SAE Paper 780256, February 1978.

[167] Thompson, "Fuel Economy Effects of Tires", Report SDSB 79-13, Standards Development and Support Branch, ECTD, EPA, February 1978.

-0.20 City and -0.19 Highway[168]; this gives a 55/45 MPG sensitivity of -0.55% per psi.

Using the surveys' tire pressure distributions and the above MPG sensitivity value, the overall MPG effects are as shown in the table:

Tire Pressure Surveys and Estimated MPG Effects

		Underinflated Tires:		Other Tires:		
Source	Number Surveyed	MPG Loss	Fraction of All Tires	MPG Gain	Fraction of All Tires	Notes
Viergutz	8900	3.1%	70.7%	1.9%	29.3%	Chicago, radials
Goodrich	6100	3.7%	56.8%	1.3%	43.2%	5 sites, sumr/wint
Uniroyal	~1000	3.4%	46.4%	1.8%	53.5%	3 sites, sumr only
Weighted Average		3.4%	63.9%	1.7%	36.1%	

If the underinflated tires were merely brought up to recommended pressure, their 3.4% shortfall would be eliminated, and fuel economy for the overall fleet would improve by 2.3%. An alternate calculation using Viergutz' conclusions for overall average underinflations, 1 to 2 psi (Summer) and 5 to 8 psi (Winter), and a 52%/48% split between summer and winter VMT yields fleet shortfalls of 1.6% to 2.7%.

If underinflated tires were inflated to match the pressure distributions of those tires which are at or above recommended levels, their fuel economy would improve by 5.3%, and that of the overall fleet by 3.4%.

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[168] Thompson and Torres, "Variations in Tire Rolling Resistance", Report LDTP 77-5, Standards Development and Support Branch, ECTD, EPA, October 1977.

d. Lubricants - Lubricants can be significant to fuel economy slippage in two ways: (1) Their effects show up in dynamometer tests, and (2) It is possible for lubricant-related MPG shortfalls to be induced by owner/drivers who replace original-fill improved oils with less fuel efficient oils or who drive in a way which uses the friction reduction of improved oils for increased performance instead of improved fuel economy. In addition, there are questions regarding availability of improved oils, and the overall energy efficiency (including process energy penalties) of their use.

In addition to our own review of data on the MPG effects of improved lubricants under a variety of conditions, we will excerpt heavily from a comprehensive report[169] on the broader aspects of these new oils, issued by the Coordinating Research Council under U.S. Army and DOT-NHTSA sponsorship. This report resulted from in-depth surveys of thirty companies and/or agencies actively involved in improved lubricants research in mid-1978.

There are two functional classes of lubricant improvements: viscosity reduction, whose benefits derive from lower viscous drag and pumping losses; and friction modification, which reduces rubbing friction in the oil film between engine surfaces. In product terms, synthetic oils may be considered a third category, exhibiting functional reductions in viscosity or friction or both.

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[169] Marshall, "Survey of Lubricant Influence on Light-Duty Vehicle Fuel Economy", Coordinating Research Council Report 502, December 1978.

Low-viscosity oils are generally "lighter", more refined oils. The CRC report indicates a fuel economy change on the order of 1% per viscosity grade change:

Oil Comparison	MPG Improvement
10W-30 vs. 10W-40	1%
5W-30 vs. 10W-30	1%
5W-40 vs. 10W-40	2%
5W-20 vs. 10W-40	2.5%-3.0%

A GM report[170] equates a 67% reduction in viscosity to a 30% reduction in overall mechanical friction, which in turn corresponds to a 5% to 6% gain in steady-state (30-55 mph) vehicle fuel economy. Amoco[171] reports a 90% reduction in viscosity to produce a 6% fuel economy gain.

Limitations to viscosity reduction include concerns for engine wear rate, engine cleanliness, increased oil consumption, and refiners' capacity to produce enough acceptable light stocks. For these reasons, many (including some auto manufacturers) prefer the friction modification route for improved oils.

Friction modifiers include colloidally-suspended solids, such as graphite or molybdenum compounds, and oil-soluble additives, such as oleates, sperm oil, tallow, etc. The CRC report arrives at average fuel economy improvements from 1% to 3.5% for steady state and cyclic driving vehicle tests, and 4.9% for field tests, of friction-improved oils. The field improvements are higher, according to this report, because actual driving is more severe than the EPA and SAE test procedures, and the friction-modified oils are more effective in severe-duty situations. A taxicab fleet, for example, showed an 8.2% improvement due to FM oils.

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[170] Goodwin and Haviland, "Fuel Economy Improvements in EPA and Road Tests with Engine Oil and Rear Axle Lubricant Viscosity Reduction", SAE Paper 780596, June 1978.

[171] Passut and Kollman, "Laboratory Techniques for Evaluation of Engine Oil Effects on Fuel Economy", SAE Paper 780601, June 1978.

Thus far, friction modifiers have been applied only to multigrade base oils (although they should improve monogrades as well) for marketing reasons: the industry makes monogrades for those users who seek cost savings via the price of the oil, and believes that those consumers who don't buy multigrades--for cost reasons--will similarly avoid costlier friction-improved monogrades. In 1976 and 1977, 40% of automotive engine oils were multigrade oils[172].

Of course, viscosity improvement and friction reduction packages can be combined, with nearly additive effects, since their functions are relatively independent. The CRC report cites one source as measuring a 1.6% MPG improvement with viscosity reduction, a 1.3% improvement with friction improvement, and a 2.5% combined effect. Research on combined VI and FM packages is underway, but proceeding cautiously.

Synthetic oil can be used as a total product, or as a blending additive. One major all-synthetic 5W-20 oil is available, with a measured average 4% fuel economy improvement, according to the CRC. The primary advantages of the synthetics are good low-temperature performance and longer drain intervals; the primary disadvantage is cost.

The following table summarizes the measured fuel economy benefits of improved oils, from a number of sources[173-184]. The reference oil for all of these comparisons is SAE 10W-40, unless noted otherwise.

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[172] Oil and Gas Journal, August 1978.

Fuel Economy Effects of Improved Lubricants
(Percent Change from SAE 10W-40)

A. Engine Dynamometer Tests

Exxon[173], friction modifier, at 1250 RPM		9.1% to 12.5%
Amoco[174], friction modifier,	single cylinder	zero to 2.2%
	six cylinder	-0.7% to +2.9%
	eight cylinder	1.7% to 2.6%
synthetic 5W-20,	eight cylinder	2.3%
Atlantic Richfield[175], friction modifer,		
	steady speeds, 0.5% graphite	0.5%
	1.0% graphite	3.0%
	multimode, 0.5% graphite	2.4%
	1.0% graphite	5.1%
	vis. reduction, steady speeds	0.7% to 1.3%
CRC (Marshall, *Op. Cit.*):	average for all oils, all sources,	
	Engine Tests	2.7%

B. Vehicle Tests, Steady Speed

Amoco, chassis dyno, 50 mph, 15 cars, friction modifier		-0.5% to +3.2%
Lubrizol[176], track tests, 1/2 @ 35 mph, 1/2 @ 55 mph, 8 cars, 8000 miles each		
	vis. reduction	1.4%
	10% synthetic	1.8%
	Full synthetic 5W-20	2.3%
[required 1500 miles to reach full effect]		
General Motors[177], 14.5 minute dyno cycle, 2 speeds, friction modifier		
	(SAE 5W-30 reference oil)	-1.1% to +11.2%

C. Vehicle Tests, Cyclic Driving

Atlantic Richfield, modified 45-min. AMA cycle run 8 times (10-55 mph, 38 mph avg.)		
1%-graphite friction modifier,	dyno tests	1.9% to 7.2%
	10-mile road route, cold start	6.0% to 7.1%
	52-mile road route, hot start	3.5% to 4.2%
[required 600 miles to reach full effect, 900 miles to lose effect after drain]		
General Motors[178], GM City-Surburban cycles, 3 cars		
Hot Start, low-vis commercial lubes in engine,	transmission, rear axle	1%
Hot Start, low-vis experimental lubes in engine,	transmission, rear axle	3.8%
Cold Start, low-vis commercial lubes in engine	and rear axle	4.8% to 11.0%

C. Cyclic Driving, cont'd.

Univ. of Michigan[179], SAE J1082 track tests, 7 cars		
Best friction modifier, 3 cars,	Urban Cycle	11%
	Suburban Cycle	4%
	Interstate Cycle	4%
CRC, average, all oils, all sources, SAE J1082 Tests		2.3%
Lubrizol, hot start EPA dyno tests, 3 cars		
Friction modifier,	EPA City	-1.2% to +2.2%
	EPA Highway	0.3% to 2.3%
Vis. reduction,	EPA City	-0.7% to +1.2%
	EPA Highway	1.0% to 2.8%
Amoco, std. EPA dyno tests, 2 cars, Friction modifiers,	EPA 55/45	-0.5% to +2.2%
[required 1500-1800 miles to reach full effect]		
Exxon, std. EPA dyno tests, 6 cars,		
Friction modifier,	EPA City	0.1% to 10.2%
	EPA Highway	1.9% to 14.9%
	EPA 55/45	(average) 5.5%
General Motors[178], improved lubes in engine and rear axle		
Low-vis. lubes in engine and axle, (3 cars)	EPA City, 0.5% to 2.9%, 1.7% avg.	
	EPA Highway, -0.3% to +2.0%, 0.7% avg.	
	EPA 55/45, 0.4% to 2.3%, 1.3% avg.	
Synthetic in engine, low-vis. in axle, (1 car)	EPA City	0.4%
	EPA Highway	2.4%
	EPA 55/45	1.1%
CRC, average, all oil-soluble FM's,	EPA City	2.3%
	EPA Highway	1.6%
CRC, average, 5W-20 synthetic, 20 domestic cars,	EPA City	3.2%
	EPA Highway	1.6%
8 import cars, 5W-20 synthetic vs. SAE 40,	Hot EPA City	4.6%
	Cold EPA City	6.8%
CRC, average, all oils, all sources,	EPA 55/45	2.0%

D. Field Tests

Exxon, friction modifier, 19 cars, 6000 miles

Range	zero to 7.1%
Average	4.6%

[required 1500 miles to reach full effect]

Climax Molybdenum[181], molybdenum disulfide friction modifier

7 cars, 102,000 miles	3.4%
10 cars, 395,000 miles	3.7%
23 school buses, 214,000 miles	4.6%

Atlantic Richfield [182], graphite friction modifier	4.9%
CRC, average, all oils, all sources, Field Tests	3.4%

E. Rear Axle Lubricants Alone

Ford[183], lab tests and computer simulations, synthetic vs. SAE 90W,

EPA tests, 70°F	<1%
Short trip winter driving	∿5%

Edwin Cooper[184], friction modified lube vs. SAE 80W-90,

EPA Highway test with 50% increase in road load HP	2.0 to 2.2%
Field tests	3.2%

General Motors [178], low-vis lube (SAE 75W) vs. SAE 90W, 2 cars,

30 mph	0.3% to 0.6%
55 mph	0.6% to 0.8%

[173] Waddey, et. al., "Improved Fuel Economy via Engine Oils", SAE Paper 780599, June 1978.

[174] Passut and Kollman, Op. Cit.

[175] Broman, et al, "Testing of Friction Modified Crankcase Oils for Improved Fuel Economy", SAE Paper 780597, June 1978.

[176] Riester and Chamberlin, "A Test Track Comparison of Fuel-Economy Engine Oils", SAE Paper 790213, February 1979.

[177] Caracciolo and McMillan, "Effect of Engine Oil Viscosity on Low-Temperature Cranking, Starting, and Fuel Economy", SAE Paper 790728, June 1979.

[178] Goodwin and Haviland, Op. Cit.

[179] Bennington, et. al., "Stable Colloid Additives for Engine Oils--Potential Improvement in Fuel Economy", SAE Paper 750677, June 1975.

[180] Davison and Haviland, "Lubricant Viscosity Effects on Passenger Car Fuel Economy", SAE Paper 750675, June 1975.

[181] Risdon and Gresty, "An Historical Review of Reductions in Fuel Consumption of U.S. and European Engines with MoS_2", SAE Paper 750674, June 1975.

[182] DeJovine, et al, "Consumer Fleet Testing of Friction Modified Motor Oils for Fuel Economy Benefits", NPRA paper, March 1978.

[183] Willermet and Dixon, "Fuel Economy - Contribution of the Rear Axle Lubricant", SAE Paper 770835, September 1977.

[184] Papay, "Fuel Saving Gear Oils", SAE Paper 790745, June 1979.

Availability of the options for improving oils is varied. For viscosity reduction, 5W-7.5W multigrade oils must be blended from "100-SUS" (Saybolt Universal Seconds) paraffinic base distillates. The CRC report quotes figures from Sun Oil indicating that currently 26% of total refinery lube output goes to 100-SUS base oil; accounting for non-automotive use and assuming the refined 100-SUS base fraction can increase to 49% in 1980 and 61% in 1985, projected supply and demand are as follows, in millions of barrels:

	Maximum Supply	Forecasted Demand
1980	19.1	22.9
1985	19.1	28.6

Avoidance of this shortfall would require such steps as limiting use of 5W-7.5W series oils to automotive purposes, importing refined 100-SUS base distillates, expanding domestic refining capacity and/or relying more on FM additives and/or viscosity reduction through blending with synthetics.

No availability problems are foreseen for friction modifier additives, and synthetics are described by the CRC report as reasonably available--at least for blending--for the next decade. Of the two types of synthetic base stocks most likely to see increased use, the polyalphaolefins are made almost exclusively in the U.S., with current capacity double the current demand, and the organic esters are readily available, some widely used in non-lubricant applications and obtainable from natural sources (coconut and palm kernel oils).

Total Energy Balance is concluded by the CRC report to be clearly in favor of the improved oils. Mineral oils, when highly refined, would appear to reduce lubricant yields, but refiners have other product markets for the broader boiling range cuts which are rejected. FM additives should be no problem because of the small quantities involved. For synthetics, the energy balance has been estimated as follows, for a 6000 mile drain interval and a 4% fuel economy improvement from a 15 MPG base:

Fuel saved with +4% ΔMPG, (15 gallons)	1,785,000 BTU
Net process energy increase	-107,000 BTU
Net energy saved	1,678,000 BTU

[94% of gross (vehicle) savings]

The detailed calculation is given in Appendix C.

Currently, EPA has not knowingly given approval for the use of specific "slippery lubes" in emission certification or fuel economy data vehicles, since they are not yet extensively available as replacement oils, are not uniformly classified as to fuel economy potential, and are generally more expensive. However, manufacturers are free to choose a range of oils for use in EPA test vehicles, as long as the oil chosen meets owner's manual warranty requirements; it is possible that oils that are optimum, from the fuel efficiency standpoint, have been identified within the broad range of warranty specifications, and may be used in some test cars. Whether or not these special lubricants do enter the certification process, in significant quantity, a positive road MPG slip will still occur if indeed average road MPG improvements exceed the improvements measured in the EPA tests. For respective improvements of 2.0% engine/1.0% axle, EPA, and 3.4% engine/1.5% axle, road, this positive slip will be 0.019 percent ΔMPG per percent use in the EPA fleet; for example, if 50 percent of EPA cars were to use advanced lubes, the improvements for the total fleet would be 1.48% in EPA MPG and 2.44% in road MPG, an 0.95% positive road slip. Of those cars factory-filled with improved lubes, 55% could switch to conventional engine oil at the first oil change before the fleet road MPG improvement ceased to exceed the EPA-measured improvement.

e. Vehicle Weight Load - When consumers use vehicles for carrying additional (non-passenger) weight loads, road shortfalls are created. For example, the carrying of an average of 50 lbs of tools, sporting equipment, vocational paraphernalia, etc., causes an average MPG loss of about 0.5%; if 50% of all vehicle miles are traveled with 50 extra pounds, the net fleet MPG penalty is 0.3%.

Trailer towing is an obvious example of a significant increase in weight load. Usage and size characteristics[185,186], of the two most predominant trailer types are shown below:

	Travel Trailers	Camping Trailers
Weight	>2600 lbs.	1000-2600 lbs.
Avg. Annual sales, 1970-1976	180,000	82,000
Sales as percentage of new-car and pickup truck sales	1.5%	0.7%
Estimated annual miles	3000-4000	1200-2000

The road fuel economy penalty for towing a 3000-lb. travel trailer has been investigated by Claffey[187] for a large pre-1970 car under steady cruise conditions; the penalty was found to be strongly dependent on speed, as shown below:

	20 mph	30	40	50	60 mph
GPM increase	.001	.008	.024	.039	.066
MPG decrease	1.4%	11.3%	30.0%	38.7%	48.6%

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[185] Automotive News, 1977 Market Data Book Issue, April 1977.

[186] Personal Communication, numerous recreational vehicle dealers in Southeast Michigan, 1979.

[187] Claffey, "Running Costs of Motor Vehicles as Affected by Road Design and Traffic", NCHRP Report 111, 1971.

The fuel economy penalty for trailer towing in cyclic driving is estimated using average weights of 1800 lb. for camping trailers, 3000 lb. for travel trailers, and 4000 lb. for the towing vehicles, and EPA cycle MPG sensitivities of -0.39 City and -0.49 Highway. The resulting 55/45 MPG penalty estimates are 19.5% for towing camping trailers and 32.5% for towing travel trailers. Annual MPG penalties of 2.4% occur for vehicles which tow camping trailers 10% of their VMT, and 8.8% for those which tow travel trailers for 20% of their VMT.

All of these weight effects are estimated to combine into an annual average MPG shortfall of 0.4% for the overall fleet.

4. Simulation Variance

The preceding road slip discussions dealt with conditions which are--or are capable of being--different from the standardized conditions of the EPA tests, and indeed different from generally accepted "standard test conditions" used in all systematic research. The influences to be discussed next are related not to conditions which the tests knowingly depart from, but to effects that the test does attempt to simulate.

a. Low-Speed Dynamometer loading - Dynamometer power absorbers are calibrated at 50 mph to match either the road load measured at that speed for the specific vehicle, or a representative average 50 mph road load calculated from an equation, based on vehicle specifications. At speeds other than 50 mph, the load curve applied by the dynamometer may or may not exactly match the vehicle's road load for those speeds.

A comprehensive comparison[188] of dynamometer and actual road power loading over the 0-60 mph speed range was conducted by EPA on a total of 65 cars: 61 1975 models and four 1973-1976 models. Ten of the cars, 15%, were found to be overloaded by the dynamometer at speeds below 50 mph, and 55 cars, 85%, were underloaded by the dynamometer at low speeds.

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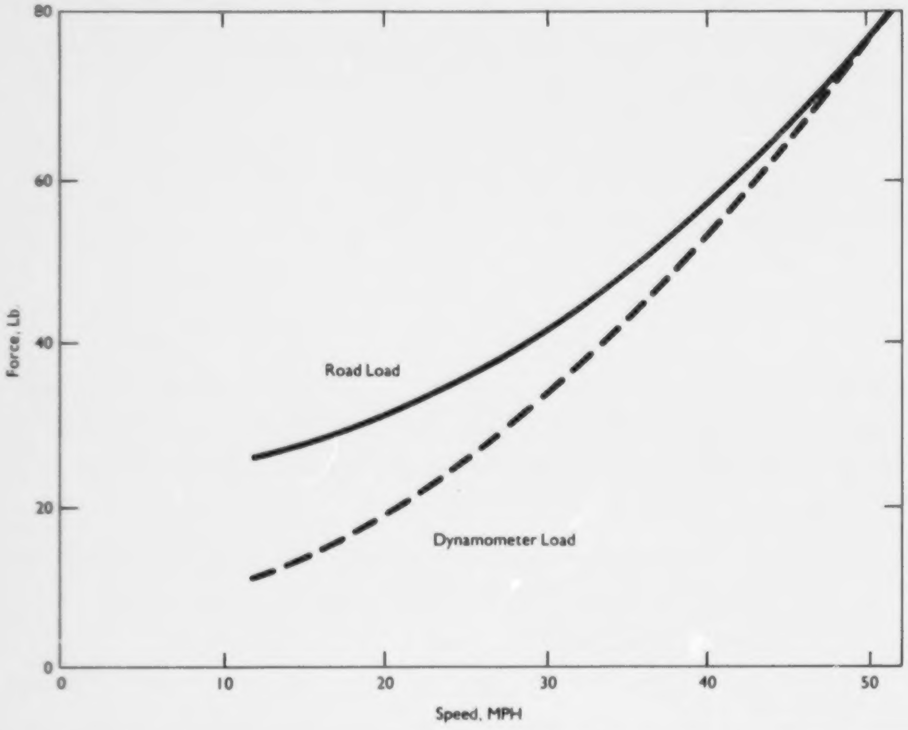
[188] Thompson and Torres, "Comparison of Dynamometer Power Absorption Characteristics and Vehicle Road Load Measurements", Report LDTP 77-3, Standards Development and Support Branch, ECTD, EPA, July 1977.

Average dyno overload at 20 mph for the ten cars was 6.2%, and average 20 mph underload for the 55 cars was 24.8%. The figure is an example of road and dyno loadings for a dyno-underloaded car.

FIGURE 57. Typical Low-Speed Dynamometer Underloading



The road load sensitivity coefficients in Section IV.A.3 are not applicable to this effect, since they were developed based on 50 mph road load, which by definition is the match point for the data of concern here. Our estimate of the shortfall/overage effect of this item is based on the calculation[189] that road load-related energy constitutes 48.8% of total EPA City cycle energy, and an assumed sensitivity of City MPG to total cycle energy of -0.6. It is also assumed that low-speed dyno misloading does not affect Highway cycle MPG.

With these assumptions, we estimate a road MPG shortfall of 3.3% for dyno-underloaded cars (85% of all cars) and a road MPG overage of 0.9% for dyno-overloaded cars (15%). Total fleet shortfall would be 2.7%.

b. Tire/Dynamometer Interaction - The two tires in contact with the dynamometer rolls are the link through which the dynamometer absorbs power from the vehicle; in a perfect simulation, the interaction between these two tires and the dyno rolls would match the power requirement of the vehicle operating with four tires on the road.

Two aspects of tire/dyno interaction have been found to differ slightly from road experience: the relative dynamometer response of tires of different ply constructions, and differences in rotational speed between the tires and the two separate dyno rolls.

Tire Construction affects fuel economy differently on the dynamometer than in actual driving; this has been documented by Ford[190,191] GM[192], and EPA[193,194].

Crum[190] investigated the rolling resistance of H78-15 bias-belted and HR78-15 radial tires on dynamometers and on the road, with results as follows, in terms of tire power consumption:

Rolling Resistance HP @ 30 mph

	Bias-belted:		Radial:	
	25 psig	45 psig	25 psig	45 psig
Twin-roll dyno (2 tires)	3.8	3.1	4.6	3.9
Road (4 tires)	3.9	3.3	3.8	2.2

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[189] Thacker and Smalley, Op. Cit. (152)

[190] Crum, "Road and Dynamometer Tire Power Dissipation", SAE Paper 750955, October 1975.

[191] Unpublished data furnished to EPA by Ford Motor Co., 1975.

[192] Stempel and Martens, "Fuel Economy Trends and Catalytic Devices", SAE Paper 740594, August 1974.

[193] EPA Dyno/Track Test Project, Phase II (Unpublished).

[194] Burgeson, "Clayton Dynamometer-to-Road Tire Rolling Resistance Relationship", Report LDTP 78-09, Standards Development and Support Branch, ECTD, EPA, April 1978.

Ideally, two tires at 45 psi cold inflation pressure on a twin-roll dynamometer (the EPA conditions) should have the same power consumption as four tires at recommended pressure on the road. Crum's data show that radial tires are loaded about the same on the dyno and the road (3.9 vs. 3.8 HP), while bias-belted tires are significantly underloaded on the dyno (3.1 vs. 3.9 on the road). Reference 194 found similar results when comparing tire types over the transient conditions of the EPA City cycle, as shown below:

	Dyno Tire Energy/Road Tire Energy
Radials	0.925
Bias-belted	0.695
Bias	0.745

Using rolling resistance sensitivities of -0.20 City and -0.19 Highway[195], these data would indicate road shortfalls of 1% for radials, 6% for bias-belted, and 5% for bias ply tires. Using new-car tire sales fractions[196] of 69% radial, 18% bias-belted, and 13% bias ply, these figures translate to a fleet road MPG shortfall of 2.5% due to the tire type malsimulation, for pre-1979 vehicles.

Direct vehicle measurements more or less corroborate this analysis. The following table lists radial vs. non-radial MPG comparisons for dyno tests and road/track tests: These data (using pre-1979 test procedures) show a radial tire 55/45 MPG superiority of 3.7% on the road, but a radial tire inferiority of 1.5% on the dynamometer.

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[195] Thompson and Torres, Op. Cit. (168).

[196] Modern Tire Dealer, January 1979.

Effect on MPG, Radial Tires
vs. Bias or Bias-belted Tires

		EPA City	EPA Hwy	30 mph	50 mph
A.	Road/Track Tests				
	Ford[191], 2 cars	+3.7%	+4.2%	--	--
	Ford[197], 28 cars	+4.2%[198]	--	+4.6%	+4.0%
	GM[192], 3 cars	--	+2.6%	--	--
	Hurter[199], 4 cars	+2.0%	--	--	+3.0%
	EPA[193], 6 cars	+3.8%	+3.6%	+2.3%	+2.8%
	Bezbatchenko[197], 4 cars	--	--	+6.4%	+7.0%
	Firestone[197], 1 car	--	--	+8.3%	+8.6%
	Weighted Average	+3.9%	+3.4%	+4.5%	+4.1%
B.	Dyno Tests				
	EPA, 6 cars	-0.2%	-1.1%	-5.4%	-1.4%
	Honda[200], 1 car	-6.0%	-7.8%	--	--
	Ford[191] (computer model)	-2.5%	-4.2%	--	--
	GM[192], 3 cars	--	-1.2%	--	--
	Weighted Average	-1.2%	-2.0%	-5.4%	-1.4%

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[197] Ford Motor Co., "Fuel Economy Improvement with Radial Ply Tires", May 1974.

[198] Ford City/Suburban Cycle

[199] Hurter et al, "A Study of Technological Improvements in Automobile Fuel Consumption", Report DOT-TSC-OST-74-40, December 1974. (computer model).

[200] Unpublished data.

Again using the 1978 new-car sales fraction of 69% for radials, a fleetwide road MPG shortfall of 1.6% is indicated for 1978 models. The road shortfalls are slightly different for prior model years, due to different sales splits for the various tire types for those years:

Road MPG Shortfall due to Malsimulation of Tire Type	
1975	2.0%
1976	1.8%
1977	1.7%
1978	1.6%

For 1979 and later models, this particular shortfall has been reduced; the tire type malsimulation has been corrected by EPA by means of an adjustment factor for tire type in the road load setpoint equation.

An additional road MPG shortfall can occur, and is believed to be occurring, due to owners switching from original equipment radial tires to aftermarket non-radials. It has been estimated[201] that 15% of new-car radials are replaced with non-radials. This gives an estimate of 0.5% for the consumer-induced shortfall. This shortfall will continue if consumer tire-switching continues at a 15% rate. For newer tires which have even larger road MPG advantage over non-radials ("P-metrics" and other higher pressure radials), the shortfall due to switching will be larger than these figures by a factor of about three.

Tire Slip and differences in rotational speed between the two dynamometer rolls have only recently been investigated[202,203]. The loading applied to a vehicle on the twin roll dynamometer is transmitted mainly through the front roll, while speed measurement is based on the rotation of the rear roll. If the tires in the roll cradle slip relative to the front roll, the vehicle is allowed to "accumulate mileage" for a less than realistic expenditure of energy, giving it an MPG benefit which would not occur on the road. The energy error--which relates to gallons consumed--has been estimated to be in excess of 4%, and the speed error--which relates to miles traveled--is an additional 1%. When the rolls are mechanically coupled, these errors are eliminated, and the resulting decreased fuel economy is a better simulation of road fuel economy. The MPG difference between the standard dyno configuration and the coupled-roll configuration gives an estimate of the magnitude of the road shortfall attributable to this effect, and is shown below. The first and third vehicles represent unpublished EPA test data, and the second vehicle's data is from Reference 203.

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[201] Thompson, Op. Cit. (167).

[202] Yurko, "Computer Simulation of Tire Slip on a Clayton Twin Roll Dynamometer", Report 79-10, Standards Development and Support Branch, ECTD, EPA, February 1979.

[203] Yurko, "A Track to Twin Roll Dynamometer Comparison of Several Different Methods of Vehicle Velocity Simulation", Standards Development and Support Branch, ECTD, EPA, June 1979.

MPG Effect of Coupling Dynamometer Rolls

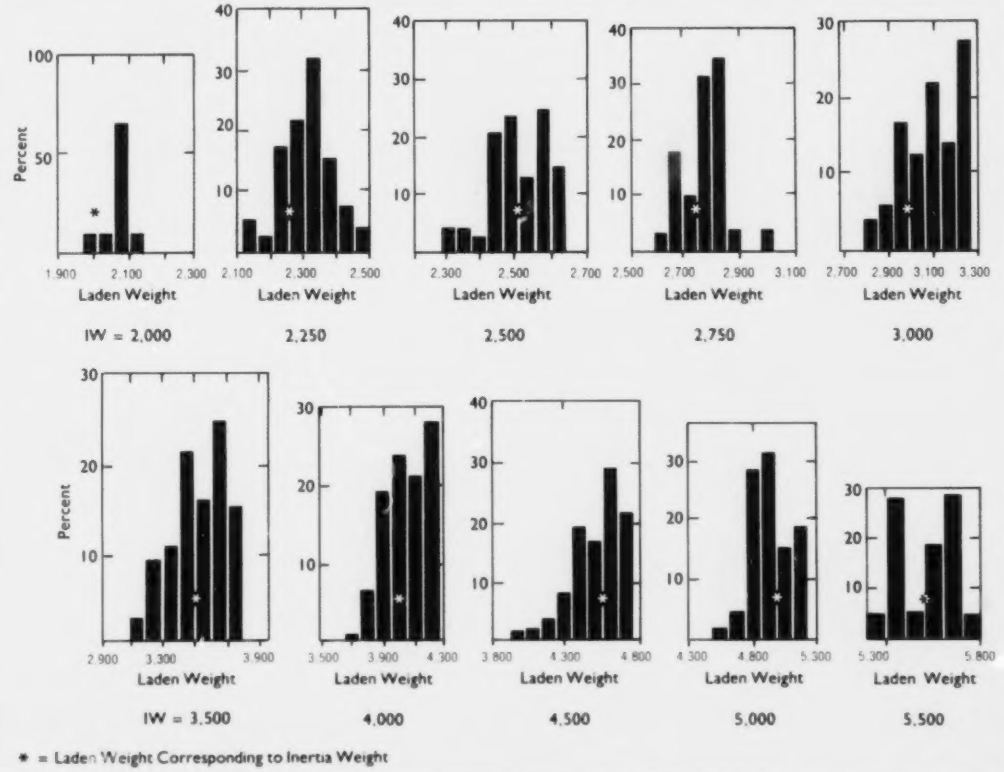
	EPA City Cycle	EPA Highway Cycle
Subcompact Car	-0.54%	-3.3%
Intermediate Car	--	-4.0% (50 mph cruise)
Large Car	-3.3%	-5.3%

If the car size difference implied by the numbers is real, overall 55/45 MPG road shortfalls due to dynamometer tire slip would be 2% for small cars and 4% for large cars. The shortfall for the overall fleet is estimated at 3.4%.

c. Weight Class Distributions - Vehicle weight simulation is based on "laden vehicle weights", determined by adding 300 pounds to specified vehicle curb weights. Due to the nature of the dynamometer equipment, however, it is not possible to set test weights at the exact value corresponding to each vehicle's laden weight; instead, a finite number of discrete test weights are employed, and each vehicle is assigned to the test weight class nearest its laden weight. If the true vehicle laden weights within each weight class were uniformly distributed around the class weight, those vehicles which were heavier than the class weight, and were therefore tested slightly under-loaded, would be balanced off by vehicles below the class weight which were tested slightly over-loaded.

We have found that these distributions are not exactly uniform, however. As one example, the figure shows laden weight distributions within each inertia weight class for the 1977 Certification cars. It is clear that in most classes there are more cars above the nominal class weight than below. Considering the relative fuel economy effects of the respective underloadings and overloadings, and the sales distributions among the weight classes, these distributions result in a fleet fuel economy loss of 1.0% on the road. For the five lower weight classes--2000 through 3000 pounds, the loss is 1.7%; for the five higher classes, it is 0.5%. Initial steps have been taken in model year 1980 to reduce the potential for weight class maldistribution, via modifications to the weight classification system.

FIGURE 58. Distribution of Lt. Duty Vehicle Laden Weights Within Inertia Weight Classes (1977)



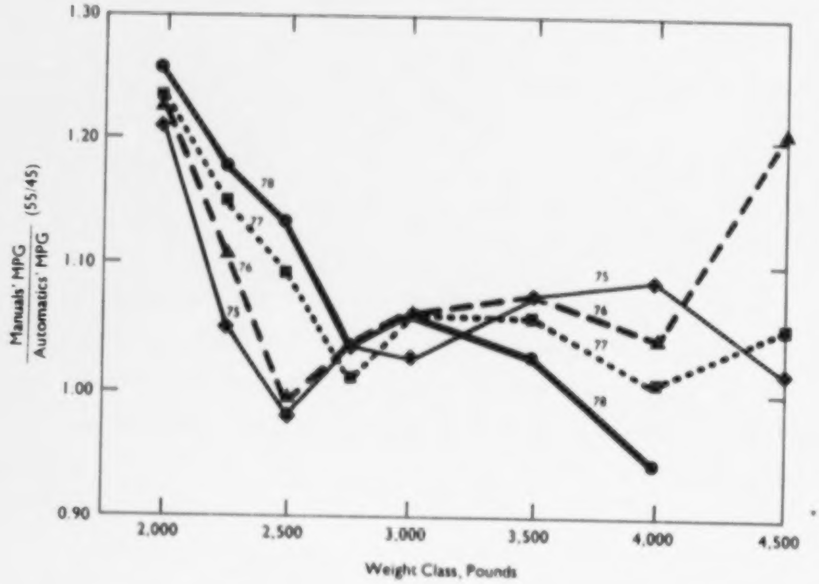
d. Manual Transmissions - As was noted in the design parameter sensitivity study in Section IV.A.3, manual transmissions' EPA MPG advantage over automatics appears to have increased during the 1975-78 time period. The next table shows this trend, from the sensitivity study.

$\frac{\text{Manual MPG}}{\text{Auto MPG}}$, Matched Cars

	EPA City	EPA Hwy	EPA 55/45	Chg. from 1975
1975	1.000	1.133	1.045	--
1976	1.011	1.129	1.052	+0.7%
1977	1.031	1.152	1.073	+2.7%
1978	1.034	1.129	1.067	+2.1%

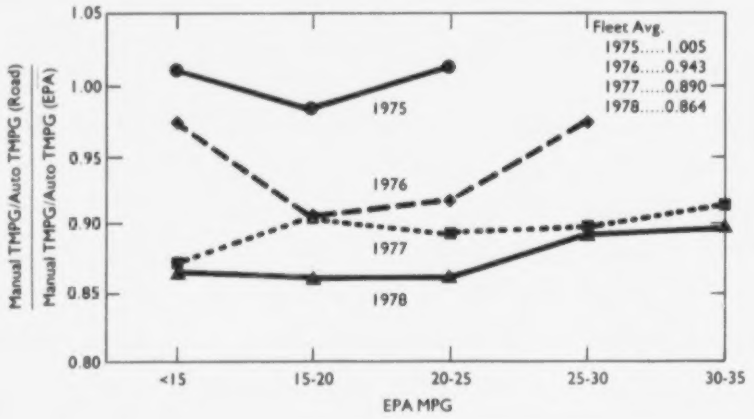
The next figure illustrates the ratio of manuals' 55/45 MPG to that of automatics, for each EPA weight class; the trend noted above can be seen clearly in the lighter weight classes.

FIGURE 59. Comparison of Manual Transmission MPG to Automatic MPG, at Constant Weight



Data furnished by DOE on EPA-to-road MPG relationships for the two transmission types were used to determine road manual-to-automatic factors. At a given EPA MPG level, there can be significant differences in average vehicle weight between automatics and manuals; hence weight normalization is required in the use of the DOE data. This was accomplished by using the parameter "ton-miles per gallon". The ratio of manual TMPG (MTMPG) to automatic TMPG (ATMPG) is a measure of relative weight-normal fuel efficiency between the transmission types, and the grand ratio of Road MTMPG/ATMPG to EPA MTMPG/ATMPG is a measure of how well the EPA transmission comparison is matched on the road. The next figure shows this grand ratio as a function of EPA MPG level.

FIGURE 60. Model Year Trends in Road and EPA Transmission MPG Relationship



This figure shows that the road and EPA manual-to-automatic ratios were essentially equal in 1975, but diverged in each of the succeeding three model years. While manuals enjoyed a growing advantage over automatics in the EPA tests, they appear to have suffered a growing disadvantage on the road, as shown in the following table.

Manual MPG vs. Automatic MPG

	EPA 55/45	Road	Total Road Discrepancy for Manuals
1975	4.5% better	5.0% better	0.5% better
1976	5.2% better	0.8% worse	5.7% worse
1977	7.3% better	4.5% worse	11.0% worse
1978	6.7% better	7.8% worse	13.6% worse

This increasing road slip is not amenable to straightforward explanation. The apparent improvement in EPA MPG with time has been shown to be the result of increased manufacturer usage, in the EPA tests, of manual transmission shift schedules tailored for good fuel economy and low emissions, but unrepresentative of what could be expected in consumer driving[204-206]. The tightening of shift point specifications by EPA beginning with the 1979 model year has decreased or eliminated further usage of unrepresentative shift schedules, and restored the test procedure to 1975 comparability; this should correct that portion of the shortfall. The loss in manuals' advantage on the road could be due to differential usage of manual vs. automatic vehicles, and/or increasingly fuel-inefficient shifting by consumers. If this is the case, it is not a clear issue of inexact simulation, but rather a question of whether vehicles driven differently should be tested differently.

At any rate, the overall fleet shortfalls corresponding to the values above can be determined by introducing the relative manual and automatic sales fractions. The next figure gives the fleet average values for 1975-78, and also illustrates manual transmissions' sales penetration as a function of vehicle test weight. Below about 3000 pounds, more than half of passenger cars use manual transmissions.

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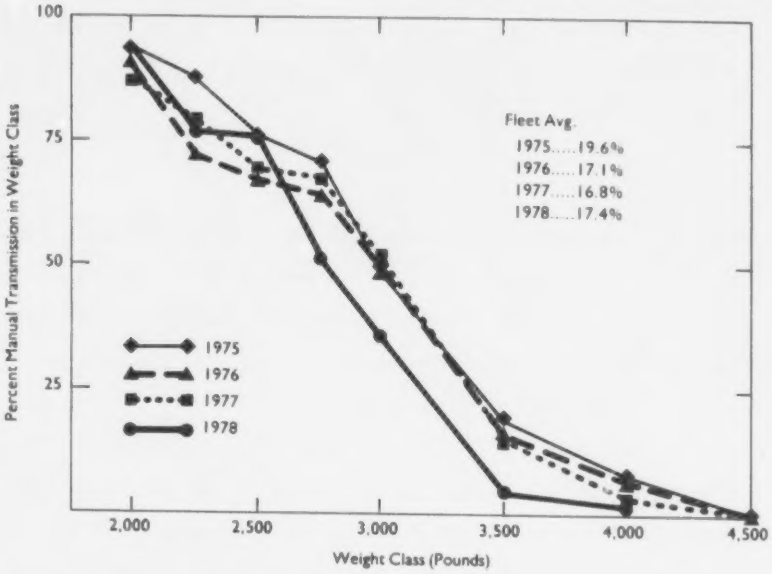
[204] Hutchins, "The Effects of Manual Transmission Shift Points on Emissions and Fuel Economy of a 1977 Chevrolet Chevette when Tested by the Hot LA-4 Procedure", Report 77-15, Technology Assessment and Evaluation Branch, ECTD, EPA, December 1977.

[205] Hirabayashi, "Manual Transmission Shift Point Study", GM Environmental Activities Publication A-3646, August 1978.

[206] Rykowski, "Shift Schedules for Emissions and Fuel Economy Testing", Report LDTP 77-6, Standards Development and Support Branch, ECTD, EPA, November 1977.

FIGURE 61. Transmission Type Sales Fractions, by Vehicle Weight



Using the fleet sales fractions and the "Total Road Discrepancy" figures from the preceding table, the road shortfalls for the overall fleet are estimated to be 1.0% in 1976, 1.9% in 1977, and 2.5% in 1978.

e. Power Accessories - All accessories cause fuel economy losses due to their weight, and power-consuming accessories cause additional fuel economy losses due to hydraulic or electrical power consumption. The use of power accessories in the U.S. car market is significant and growing with time[207,208], as in the next table:

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[207] Automotive News, 1976 and 1977 Market Data Book Issues.

[208] Forrest, et al, "Passenger Car Weight Trend Analysis (2 Vols.)", Report EPA-460/3-73-006a, January 1974.

Power Accessory Usage

	1972	1976		1977	
	Domestic	Domestic	Import(Est.)	Domestic	Import(Est.)
Power Seats	--	16.7%	<5%	21.2%	<5%
Power Windows	--	22.7%	<5%	27.2%	<5%
Backlight Defogger	--	28.9%	∿15%	35.1%	∿15%
Air Conditioning	70%	74.9%	∿25%	81.9%	∿30%
Power Brakes	69%	81.8%	∿10%	91.4%	∿15%
Power Steering	86%	90.8%	∿30%	95.8%	∿35%

The MPG penalty due to weight alone for air conditioning, power steering, power brakes and power windows combined has been estimated[209] at 4% for urban driving and 3% at 70 mph.

The weight-related MPG penalty does not figure in EPA-to-road MPG shortfalls, since accessory weights are accounted for in the EPA test vehicles. However, those car buyers who opt for these items still absorb the added fuel consumption due to their weight, whether or not these accessories are operated.

The fuel consumption effects of operation of power seats and the like are not simulated in the EPA tests, but when averaged over a vehicle's life, this effect should be very, very small. Power brakes are fully exercised in the stop-and-go portions of the EPA tests, while the MPG effect of power steering is simulated only to the extent of hydraulic pump losses exclusive of turning. We do not have power steering system operational data with which to evaluate whether a measurable shortfall exists in this area.

The effects of air conditioner operation are simulated in the EPA tests by means of a 10% increase in 50 mph dynamometer road load power; vehicle air conditioners are not operated during the tests. This simulation was originally developed to represent the year-round average power increase for air conditioning, not the MPG effect for that fraction of the time an air conditioner is actually being used. With MPG sensitivities of -0.16 City and -0.33 Highway, this 10% increase in 50 mph road load imposes a 2.2% penalty in 55/45 MPG on air-conditioned models. With 70% of the total domestic and import fleet air conditioned, the fleetwide penalty corresponding to this simulation is 1.6%.

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[209] Huebner and Gasser, "General Factors Affecting Vehicle Fuel Consumption", SAE paper 730518, May 1973.

The table below gives actual power steering and air conditioner fuel consumption penalties from vehicle tests[209-220]. Some power consumption characteristics of these two accessories are also shown.

Fuel Economy Loss due to Power Accessory Operation

A. Steady Cruise

	20mph	30	40	50	60	70	80mph
Power Steering							
Huebner & Gasser[209]	--	--	--	--	--	2.4%	--
Cornell[210]	--	2.4%	2.1%	2.0%	2.0%	2.0%	2.2%
RLHP increase[211]	9.5%	6.8%	5.3%	4.4%	3.8%	--	--
Air Conditioning							
Cornell	8.1-10.4%	7.8-8.9%	6.6-8.1%	5.5-7.2%	4.3-6.7%	3.3-6.1%	3.3-5.3%
Huebner & Gasser	--	--	--	--	--	6.0%	--
Donoho[212]	--	--	--	9.4%	--	--	--
Coon, et al[213]	--	--	--	11-15%	--	10-11%	--
EPA Dyno/Track[214]	14.4%	10.7%	7.5%	5.5%	5.3%	5.3%	4.5%
RLHP increase	63%	40%	29%	23%	19%	--	--
AC horsepower, Marks[215] ("Climate control" system)							
40°F	1.4	1.7	2.0	2.5	3.3	4.6	--
70°F	2.6	2.9	3.4	4.1	4.9	5.9	--
100°F	4.4	4.7	5.1	5.7	6.6	7.6	--

B. Cyclic Driving

Scheffler & Niepoth[216] (GM City) . . . . AC + PS + Generator, 6.3%

Huebner & Gasser (Chrysler Urban) . . . . PS, 0.9%

. . . . AC, 13.0%

Air Conditioning:	EPA City	EPA Hwy	EPA 55/45
Eccleston, et al[217], 15 1969-75 cars, 110°F	10.4%	--	--
Bernard, et al[218], 40 pre-1975 cars	6.4%	--	--
Coon, et al, 1 car	4.8%	--	--
EPA Dyno/Track, 5 1976 cars, 57°-71°F	9.9%	8.0%	9.2%
Baker[219], 30 1976-78 Calif. cars, 80°F	--	--	6.0%
Spindt & Hutchins[220], 7 1972-79 cars, 80°F	6.5%	4.1%*	5.6%
90°F	8.9%	10.2%	9.4%
110°F	13.9%	17.6%	15.3%

The average in-use MPG penalty for air conditioner operation can be estimated in two ways: (1) for a 70% vehicle installation factor and a fixed EPA 55/45 penalty of 6% for AC operation, the fleet MPG effect would be 0.4%, 0.9%, and 1.3% respectively for AC duty cycles of 10%, 20%, and 30%; (2) Applying temperature adjustments to the AC penalty rather than using a fixed penalty, and considering the distribution of VMT among various ambient temperatures (Section IV.C.1.a.), the annual AC loss would be 4.0% for climate control systems, and 2.1% for standard systems. Again using a 70% vehicle AC installation factor and estimating that 1/3 of those installations are of the climate control type, the year-round penalty for the overall fleet would be 2.0%.

Thus, the EPA simulation's 1.6% MPG penalty compares well with even the worst estimate (2%) of the real-world effect that it attempts to simulate: the fleetwide, year round penalty of air conditioner usage.

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[210] Cornell, "Passenger Car Fuel Economy Characteristics on Modern Superhighways", SAE Paper 650862, Novermber 1965.

[211] EPA-calculated composite from numerous sources, unpublished.

[212] Donoho, "EPA MPG--How Realistic?", SAE Paper 780866, December 1977.

[213] Coon, et al, "Technological Improvements to Antomobile Fuel Consumption", Report DOT-TSC-OST-74-39, December 1974.

[214] EPA Dyno/Track project, Phase II (unpublished).

[215] Marks, "Which Way to Achieve Better Fuel Economy?", Seminar at California Institute of Technology, December 1973.

[216] Scheffler and Niepoth, "Customer Fuel Economy Estimated from Engineering Tests", SAE Paper 650861, November 1965.

[217] Eccleston, et al, "Ambient Temperature and Vehicle Emissions", EPA Report 460/3-74-028, October 1974.

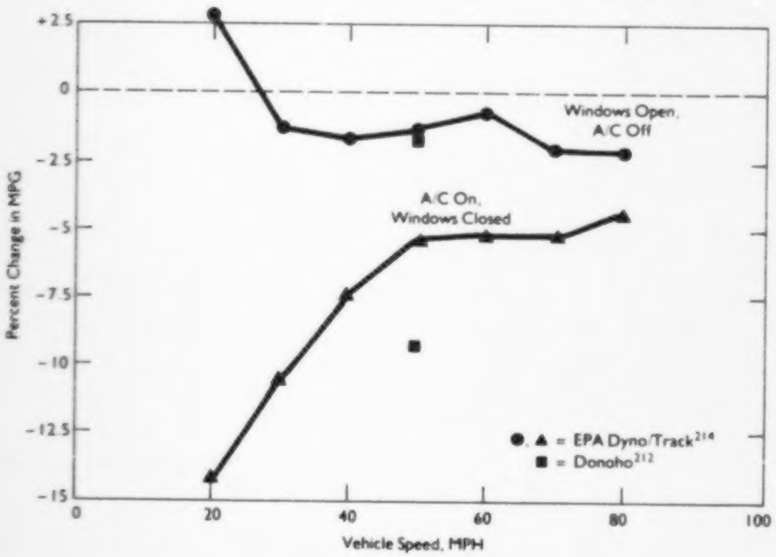
[218] Bernard, et al, "Automobile Exhaust Emission Surveillance Analysis of the FY73 Program", EPA Report 460/3-75-007, July 1975.

[219] Baker, unpublished data submitted to SAE Passenger Car and Light Truck Fuel Economy Measurement Committee, September 1979.

[220] Spindt and Hutchins, "The Effect of Ambient Temperature Variation on Emissions and Fuel Economy - An Interim Report", SAE Paper 790228, February 1979.

One more factor related to air conditioning deserves mention. An isolated instance has been reported[221] wherein a specific vehicle--at high speed--with the air conditioner operating was supposedly found to be more fuel-efficient than turning off the air conditioner and opening windows. The aftermarket air conditioner industry wasted no time in taking out a large ad[222] emphasizing the AC-favorable aspects of that isolated observation, while omitting most of the caveats. Two test projects that we know of[212,214] included measurements of this effect. The figure below shows the results. At steady cruise speeds up to 80 mph, the "windows-open" penalty remains significantly smaller than the air conditioner penalty. The curves may indeed cross at 100 mph or so for the car types tested, or at lower speeds for certain specific cars, but we must refute any assertion that, as a rule, opening vehicle windows is more detrimental to fuel economy than air conditioner operation, for any reasonable operating condition. Also, as pointed out earlier, air conditioning systems impose a full-time MPG penalty due to their weight, whether operated or not.

FIGURE 62. Fuel Economy Effects of Air Conditioning and of Open Windows



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[221] The Washington Star, September 9, 1979, at F-10.

[222] Automotive News, October 22, 1979.

f. Vehicle Cooling - in the EPA tests, vehicle cooling is accomplished by a fixed speed fan positioned in front of the vehicle grille. Tire cooling and speed-dependent air flow, as seen on the road, are not simulated. A study[223] sponsored by EPA investigated the relative cooling effects of a number of fixed-speed fan arrangements as compared with road operation, for two cars with large V-8 engines (>400 CID): a 1975 Chrysler and a 1976 Pontiac.

The author concludes that one vehicle was consistently overcooled in the dynamometer tests, while the other was consistently undercooled. Our own evaluation of the data on road and dynamometer temperatures of various vehicle components shows that, for both vehicles, road temperatures were usually lower than dynamometer tests which used the standard EPA fan arrangement. If higher dyno test temperatures are equated with higher fuel economy, this suggests the potential for a simulation-related MPG shortfall for very large engines. However, the small sample size and the absence of road fuel economy measurements in this project prevent the drawing of specific conclusions on the magnitude or even the direction of any such disparity for all vehicles. EPA is continuing to study the question of vehicle cooling.

g. Metric Slip - Metric slip is the name given to any fuel economy deviation caused by differences in the way fuel economy is measured. In contrast to some of the other slip factors which are more amenable to direct estimates of the average effect, metric slip is somewhat more amenable to a discussion of the dispersions in the different approaches.

The two general methods are, of course, the method used by EPA to determine the EPA fuel economy numbers and the method (or methods) used to determine In-Use or Road Fuel Economy.

(1) The EPA Carbon Balance Method - The method used by EPA to calculate fuel economy (the carbon balance method) is based on conservation of the mass of carbon contained in the fuel, consumed by the vehicle, and ejected in the exhaust. Knowing the amount of carbon in the exhaust and the amount of miles traveled on the tests the fuel economy can be calculated.

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[223] Sharman, "Temperature Comparison: On-Road versus Dynamometer Cooling", Final Report, EPA Contract 68-03-2412, Task 2, June 1977.

Generally the equation for fuel economy is of the form:

$$MPG = \frac{N}{D}$$

where N, the numerator, is a function of the density (grams/gallon) of the fuel and the carbon fraction (grams carbon/gram fuel) of the fuel; D, the denominator, is a function of the emissions (grams per mile) of the carbon-containing exhaust constituents and the carbon fraction (grams carbon/grams exhaust constituent) or:

$$MPG = \frac{\left(\frac{\text{grams fuel}}{\text{gallon fuel}}\right) x \left(\frac{\text{grams carbon}}{\text{grams fuel}}\right)}{\sum_i \left(\frac{\text{grams}}{\text{mile}}\text{ exhaust constituent}_i\right) x \left(\frac{\text{grams carbon}}{\text{grams exhaust constituent}_i}\right)}$$

There are some underlying assumptions involved with the equation, and some simplifications in its actual use, that can affect the fuel economy calculated.

One assumption is that all of the fuel put into the gas tank is consumed by the engine. This assumption is not totally correct. When liquid fuel is pumped into the tank, gaseous vapors are displaced, and these displaced vapors are not available to be burned by the engine. In addition, vehicles lose gasoline vapors (evaporative emissions) due to diurnal breathing and hot soak losses. These losses are not included in the fuel economy calculations[224]. When vehicles are in operation, running losses may also be experienced, which are also not measured.

Another assumption is that all of the carbon in the fuel that is consumed by the engine comes out of the exhaust tailpipe. This assumption neglects exhaust system leaks.

These two assumptions are such that the fuel economy calculated by the EPA carbon balance method tends to overestimate vehicle fuel economy.

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[224] Other fuel measurement methods, such as volumetric and gravimetric techniques, also virtually always overlook these fuel losses.

Fuel economy dispersion can be influenced by the MPG equation also. For example, at one time the "miles" value used to determine the gram/ mile parameter was defined equal to 7.5 miles for the urban cycle (its nominal length); however, considering test tolerances, not all tests are exactly 7.5 miles long. Beginning with Model Year 1978, the miles traveled are calculated based on a count of the revolutions of the dyno rolls on each test; the measurement has thereby been improved. In another equation-related concern, the equation used currently assumes that HC, CO, and CO_2 are the only carbon-containing exhaust constituents. For vehicles powered by gasoline-fueled engines, this assumption means that other carbon-containing materials which are not picked up by the Flame Ionization Detector (FID) are not counted. This tends toward an overestimate of fuel economy, since some materials such as aldehydes are not detected. For vehicles powered by Diesel engines, there is carbon in particulate emissions, which is also undetected.

Some values in the equation depend on certain properties of the exhaust constituents, such as the carbon fraction. For CO and CO_2, these fractions are known precisely, but for HC the equation's carbon fraction is not necessarily accurate for every exhaust emission control system and vehicle. Exact calculations of MPG via vehicle-specific HC carbon fraction corrections are not done at this time due to cost-effectiveness considerations.

The final concern has to do with fuel properties. The current approach is to use a constant value for the product of density and carbon fraction. In the fuel that EPA uses, there is some variability in both of these properties from batch to batch; use of a constant value for this product can contribute to dispersions in the MPG measurements.

The above fuel specification discussion only applies to discrepancies between the carbon balance equation and the fuel used by EPA in its testing. This EPA test fuel can differ in properties from the fuel actually used in the field. This difference can also lead to a difference in calculated fuel economy. Consideration could also be given to fuel density-ambient temperature relationships.

Summary - EPA's Carbon Balance Method - it appears that the carbon balance method as currently used tends to overpredict fuel economy relative to direct laboratory fuel measurements.

Calculating one single value for the MPG offset due to the way EPA uses the carbon balance calculation is difficult for two reasons. First, in-use gasoline varies substantially in its properties, and there is no one set of values to compare to. Secondly, the amount of carbon that is missed by the current procedure is not known precisely.

With the above caveats, some estimates of the offset due to the carbon balance method can be made. Using survey data[225], one can compute that the in-use value for g carbon/g fuel values ranges from 0.862 to 0.877 (EPA uses 0.866). The value for the product of g carbon/g fuel and g gasoline/gallon in use ranges from 2353 to 2424 (EPA uses 2421). Using the average values of the in-use fuels' carbon parameters, one calculates an offset of about 1%, with the EPA carbon balance calculations being high. If, however, one uses the values of the parameters that maximize the offset and adds in an estimate of 1.0 g/mile for the HC equivalent of all the carbon not accounted for, the offset could be as high as 4%, again with the EPA method being high.

(2) In-Use Fuel Economy Determinations - Two subjects are relevant in this area: the in-use fuel economy calculations performed to arrive at fleet car MPG values, and in-use fuel economy calculations performed by consumers. Further, there are some issues common to both of these in-use MPG determinations.

Fleet Car MPG - Fleet car MPG calculations are important because much of the in-use data from which overall shortfall estimates are derived comes from fleet cars.

There may be as many MPG calculation methods as there are fleets. It can happen that data on miles driven and data on gallons consumed may not be taken simultaneously on each vehicle in the fleet. Data on miles driven may be taken from periodic odometer surveys and gallons consumed may be taken from credit card receipts or from a fleet's controlled fuel supply records. This can lead to some inconsistencies in the MPG values for individual vehicles or the fleet as a whole. It undoubtedly increases the dispersion in fleet MPG values for nominally identical vehicles. Variance in either the figures for miles traveled or gallons consumed could be partially responsible for the wide dispersion seen in the road MPG values given in Section III.C.2 for 123 fleet vehicles with a 29 MPG EPA rating (high = 31 MPG, low = 3 MPG).

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[225] U.S. Department of Energy, "Composition and Octane Number of U.S. Motor Gasolines Sampled in the DuPont 1978-79 Winter Road Octane Survey", Report BETC-0012-1, September 1979.

Consider this example: a vehicle is driven for six months, delivering consistent fuel economy near 15 MPG. If the vehicle is in fleet service, and odometer readings (from the maintenance garage) do not reach the accounting computer at the same time as fuel vouchers (say, from credit card purchases), an end-of-month MPG calculation could match one month's miles with another month's gallons, giving surprising results.

Effects of Led/Lagged Mileage and Fuel Use
Figures on MPG Calculations

Month	Miles Driven	Gallons Used	Actual MPG:		Calculated MPG: (Fuel lag 1 mo.)		(Miles lag 1 mo.)	
			Month	Cumulative	Mo.	Cumulative	Mo.	Cumulative
1	1000	69.4	14.4	14.4	--	--	--	--
2	2000	135.0	14.8	14.7	28.8	28.8	7.4	7.4
3	1500	100.1	15.0	14.8	11.1	17.1	20.0	12.8
4	600	39.7	15.1	14.8	6.0	13.5	37.8	16.4
5	2100	138.4	15.2	14.9	52.9	18.0	4.3	12.3
6	1800	118.1	15.2	15.0	13.0	16.6	17.8	13.6

Rather than report that "the car gets 4 to 53 MPG", an analyst armed only with the data on the right side of the chart could use cumulative figures (13.6 to 16.6 MPG), average all of the monthly data (19.9 MPG arithmetic, 11.3 MPG harmonic), or discard outliers below 8 MPG or above 22 MPG (60% of the data) and average the remaining data (15.5 MPG arithmetic, 14.6 harmonic).

We have no data with which to evaluate the possible nationwide effects of such metric anomalies; the examples above do illustrate the potential for significant metric slips, possibly more likely to occur with fleet data than consumer data.

Consumer Car MPG - Consumer-derived MPG values can also have some metric-related dispersions. One possible error source is nonuniform sampling. We surmise that most consumers do not keep detailed records of all their mileage driven and fuel purchased, but rather that most consumers calculate MPG values only when convenient, such as on a vacation trip where one or more tanks of fuel are consumed in a relatively short time period. Such nonuniform sampling could lead to MPG results that may not be completely representative of the overall MPG performance of the vehicle.

Another consideration is that consumers might only compute tank-at-a-time MPG values and not compute cumulative MPG over several tankfulls. Using tank-at-a-time values leads to dispersion, and arithmetic averaging of these tank-at-a-time MPG values can lead to overestimates of fuel economy compared to the cumulative approach.

Variances Common to Both In-Use MPG Determinations - Both in-use sources of MPG data have possible variances associated with them in the determination of both miles driven and gallons consumed or purchased.

Variances in the miles-traveled parameter can come from a variety of causes, as listed below[226]:

Factors Affecting Odometer Mileage Accuracy

- Take-off Pinion Design Limits
- Tire Make, Tread, and Construction
- Tire Inflation Pressure
- Tire Wear
- Tire Growth
- Tire Size
- Centrifugal Effects
- Rear Axle Load

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[226] Society of Automotive Engineers, "Factors Affecting Odometer-Speedometer Accuracy", SAE Information Report J862b, April 1969.

Not all of the factors affect the odometer reading the same way, so an overall average offset in mileage measurement cannot easily be determined. SAE Recommended Practice J678 suggests that the odometer gearing ratio be such that odometer accuracy will be within the limits of -1% to +3.75% at 45 mph. From this factor alone, the allowable error favors fuel economy overestimation. In addition to the odometer effects listed previously, miles indicated can differ from actual miles driven due to wheel spin; this could be significant for vehicle operation in slippery or icy conditions, and would also result in overestimation of miles traveled and of MPG.

Determination of the "gallons" figure is subject to some variance also. The non-repeatability of fill-up level, for example, will affect tank-at-a-time calculations, as discussed earlier. In addition, gallons consumed may not always equal gallons purchased, due to fuel vapor displacement and gasoline spills during refueling. When considering the accuracy of in-use MPG determinations, the accuracy of gasoline dispensing pumps is also a factor.

(3) Summary-Metric Slip - Many slip factors in this report have been assigned numerical values which typically are the difference between the averages, or central tendencies, of two statistical distributions, one being "EPA" and the other being "In-Use". For metric slip, assigning a specific value (or even a direction) for in-use MPG slip is not feasible at this time. While certain features of the EPA measurement procedure suggest that it overestimates fuel economy, there are features of in-use measurement of miles traveled--and of in-use record keeping--which make it likely that in-use MPG can be overestimated by a margin at least as great as that of the EPA method.

5. Summary Findings: Road Slip

Fuel economy influences which are felt mainly in operation of vehicles on the road, or whose effects do not appear in dynamometer testing, are listed in the table below:

Effects of Road Slip Influences
on Fuel Economy

	Relative MPG	Fleet MPG Shortfall
Travel Environment	0.868	-13.2%
Travel Characteristics	0.975	-2.5%
Vehicle Condition	0.954	-4.6%
Simulation Variance	0.898	-10.2%

The "relative MPG" figures in this tabulation were calculated by multiplying the individual Road Slip influences' respective slip factors. Referring to Section IV.A, the three-year average Road Slip shortfall from raw DOE data was approximately 10%. The average Road Slip inferred by the results of our studies exceeds the DOE average by a factor of three.

This observation of course prompted a thorough re-examination of our analyses, with suspicions that we may have been unduly pessimistic in our assumptions. Following that re-examination, we stand by the analyses for the individual MPG influences. But the assumption of mutual independence among the many effects, and the multiplication of their respective slip factors, "stacks them together" in a way which may not reflect their real-world interaction. This realization led to the next section of the report, which does indeed confirm that the whole is not necessarily as great as the sum of its parts, when it comes to multiple fuel economy effects.

The Travel Environment category includes powerful, highly variable, and generally unpredictable MPG influences; this is obvious enough not to warrant further discussion. The relatively small overall shortfall attributed to the Travel Characteristics class, however, conceals the fact that powerful MPG influences are to be found here, too--particularly in the areas of vehicle speed and acceleration. These factors are no less variable, and no more predictable, than is the weather, but they are subject to driver control.

As regards model year differences, only the Simulation Variance category lent itself to year-by-year analysis. Two of the included factors and their shortfall trends are listed below:

Model Year Trends, Simulation Variance Items
(Average Percent Deviation from EPA MPG)

	Model Year: 1975	1976	1977	1978
Tire Type Malsimulation	-2.0%	-1.8%	-1.7%	-1.6%
Manual Transmissions	+0.1%	-1.0%	-1.9%	-2.5%

The tire type malsimulation item refers only to differences in the dynamometer response of radial and non-radial tires, and does not relate to other dynamometer loading factors.

While the time trends in these items' shortfalls are not of national fuel consumption significance, it is important to note that these test shortcomings were recognized and corrected in the EPA test procedures for 1979 and later model years, driving their shortfall-producing potential toward zero. Another Simulation Variance factor which we believe has contributed to MPG shortfalls on the road is the system of assigning vehicle test weights to discrete classes. Beginning with model year 1980, we think there will be a reduction in test weight-related MPG discrepancies, due to the use of smaller weight increments between test weight classes. The remaining Simulation Variance factors are receiving, and will continue to receive, further study.

Finally, the Road Slip studies did reveal a number of ways in which the higher-MPG cars can suffer worse MPG shortfalls. We find Travel Characteristics influences such as trip length, average speed, cold-start fraction, and urban vs. rural location for smaller cars to be typically in directions detrimental to fuel economy. MPG sensitivities to low temperatures and wind effects also appear to be more detrimental for the smaller cars.

D. Fuel Economy Effects in Combination

For most of this report, fuel economy effects of various influences have been expressed as "slips": ratios of the MPG under the condition of interest to the MPG under the standard conditions of the EPA tests. A simple way to estimate the net effect of several influences acting in combination would be to multiply the individual slip factors. However, as discussed below, other approaches are preferable to this simplistic method.

1. Mathematical Implications

Fuel economy, in MPG, can be expressed as a function of power (hp), brake specific fuel consumption (bsfc, in lb/bhp-hr), speed (mph), and fuel density (d_f, in lb/gallon):

$$MPG = \frac{mph \times d_f}{hp \times bsfc}$$

At fixed speed and fuel density, the MPG slip for a change in hp is:

$$\frac{MPG_i}{MPG_o} = \frac{hp_o \times bsfc_o}{hp_i \times bsfc_i}$$

$$\text{or:} \quad \frac{MPG_i}{MPG_o} = \frac{hp_o \times bsfc_o}{(hp_o + \Delta hp_i) \times bsfc_{hpi}}$$

If the fuel economy slips for N different hp changes are measured separately, and the combined effect of these changes estimated by taking the product of the individual slips, we have:

$$\frac{MPG_{N=n}}{MPG_o} = \prod_{j=1}^{n}\left(\frac{MPG_j}{MPG_o}\right)$$

$$= \frac{hp_o \times bsfc_o}{(hp_o + \Delta hp_1) \times bsfc_{hp1}} \times \frac{hp_o \times bsfc_o}{(hp_o + \Delta hp_2) \times bsfc_{hp2}} \times \ldots \times \frac{hp_o \times bsfc_o}{(hp_o + \Delta hp_n) \times bsfc_{hpn}}$$

$$\text{or:} \quad \frac{MPG_{N=n}}{MPG_o} = (hp_o \, x \, bsfc_o)^n \, x \prod_{j=1}^{n} \left(\frac{1}{(hp_o + \Delta hp_j) x \, bsfc_{hpj}} \right)$$

But if all the Δhp's are applied at once, the MPG slip effect is:

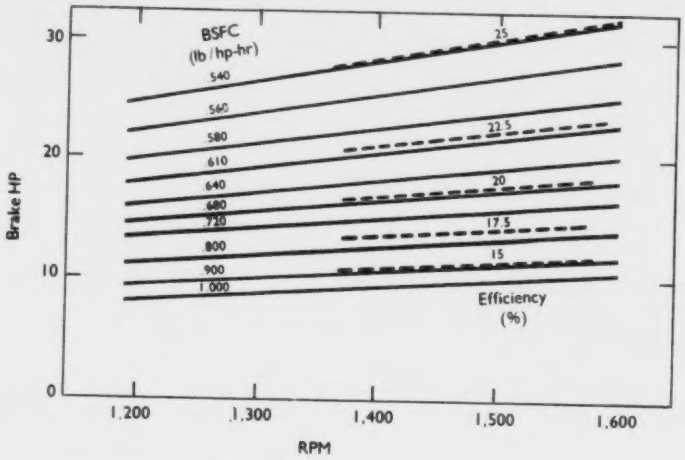
$$\frac{MPG_{N=n}}{MPG_o} = \frac{hp_o \, x \, bsfc_o}{\left(hp_o + \sum_{k=1}^{n} \Delta hp_k \right) x \, bsfc_{hp\Sigma}}$$

It is clear that the two methods are not at all mathematically equivalent, and would produce equal results only by coincidence, or due to some special interrelationship of the variables which is not apparent.

2. Engine Map Considerations

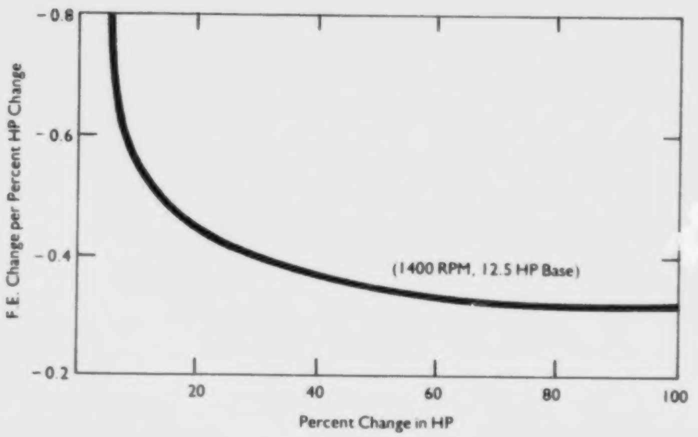
It is well known that automotive engines generally become more efficient (i.e., bsfc decreases) as loads are increased. The figure, a portion of an engine fuel consumption map, illustrates.

FIGURE 63. Portion of a Typical Engine Map (Early 1970's Domestic V-8)



Because of this engine map characteristic, small changes in load have a proportionately larger fuel economy effect than large load changes, as shown in the next figure.

FIGURE 64. Sensitivity of Fuel Economy to Change in Power Load (From Previous Engine Map)



Thus, simply multiplying the MPG slips for a number of relatively small load changes -- each measured at high MPG sensitivity -- overestimates the effect of simultaneous application of all those load changes. As a simple example, four load increases of 5% each, at a sensitivity of -0.75% ΔMPG per %Δhp, would each result in an MPG loss of 3.75%, or a slip factor of 0.9625. Using the product of the slip factors, one would estimate the total MPG loss to be 14.2%, from:

$$\frac{MPG_{N=4}}{MPG_o} = (0.9625)^4 = 0.858$$

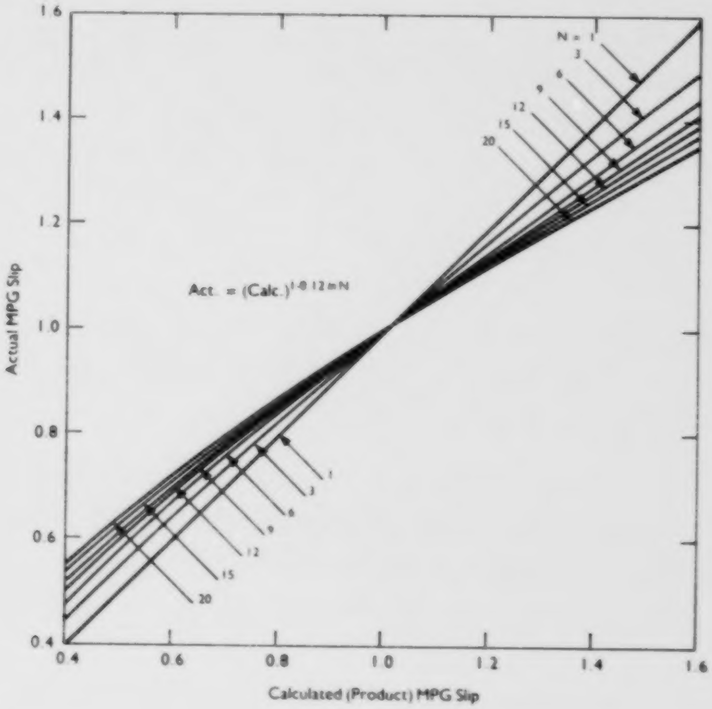
A total load increase of 20%, however, with a sensitivity of -0.45% ΔMPG per %Δhp, gives a loss of only 9.0% (slip factor = 0.910).

Analysis based on this engine map yields the following relationship for "derating" the calculated MPG slip of N separate load changes:

$$\text{Actual}\ \frac{MPG_N}{MPG_O} = \left(\text{Calculated}\ \frac{MPG_N}{MPG_O}\right)^{\phi}$$

where $\phi = 1-0.119[\ln(N)]$ and the calculated slip is the product of the individual slips. The equation is plotted in the next figure.

FIGURE 65. Relation for Derating Calculated MPG Effect of Multiple Influences



General use of this equation should be made with caution, since:

- this adjustment is derived from a simple point-to-point type of analysis of one region of one specific engine map, and may not accurately reflect MPG behavior for other engines, or the complex transient conditions of stop-and-go driving;

- the adjustment is based on engine load effects, and does not necessarily apply to other MPG influences, such as ambient temperature.

3. Actual Examples

In a study of engine modifications for improved fuel economy, vanBasshuysen *et al*[227] report the following changes in fuel consumption for six separate factors, and their effect when combined. All changes are based on hot start EPA City cycle tests.

	Change in Fuel Consumption	Change in Fuel Economy	
		Percent	ΔMPG (25 MPG base assumed)
Lightweight pistons	-1.8%	+1.8%	+0.5
Softer valve springs	-1.5%	+1.5%	+0.4
Cylinder head cooling	-2.2%	+2.2%	+0.6
Hi-temp thermostat	-2.8%	+2.9%	+0.7
Lighter engine oil	-3.2%	+3.3%	+0.8
Decel. fuel cutoff	-3.2%	+3.3%	+0.8
All, combined (actual)	-12.7%	+14.5%	+3.6
(calculated, sum)	-14.7%	+14.9%	+3.8
(calculated, product)	-13.8%	+16.0%	+4.0

The combined slip is seen to be less than that calculated from the separate slips, if the calculation is done multiplicatively. If the fuel economy changes are added, either as absolute values or percentages, a better estimate of the combined effect is obtained.

Applying the power equation developed in the preceding section, we find that $\phi = 1-0.049 \ln(N)$ produces the same results as the combined-effects measurement, i.e.

$$\frac{MPG_6}{MPG_o} = (1.160)^{1-.049\,ln(6)} = 1.145, \quad \Delta = +14.5\%$$

from the fuel economy slip product;

$$\frac{MPG_6}{MPG_o} = (0.862)^{1-.049\,ln(6)} = 0.873, \quad \Delta = -12.7\%$$

from the fuel consumption slip product.

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[227] vanBasshuysen *et al*, "Fuel Ecomomy Improvements by Reduction of Friction Losses and Other Measures", Audi NSU Auto Union AG, November 1979.

Data presented by Porter[228] on nine vehicle improvements shows the following fuel economy effects for the EPA 55/45 test:

	Change in Fuel Economy		Change in Fuel Consumption
	ΔMPG (Base=19.4 MPG)	Percent	
Reduced frontal area	+0.2	+1.0%	-1.0%
Reduced weight	+3.4	+17.5%	-14.9%
Modified cooling fan	+0.3	+1.5%	-1.5%
Wide ratio transmission	+0.3	+1.5%	-1.5%
Optimized torque converter	+0.1	+0.5%	-0.5%
Var. disp. transm. pump	+0.8	+4.1%	-4.0%
Reduced brake drag	+0.3	+1.5%	-1.5%
Reduced tire roll'g resistance	+0.7	+3.6%	-3.5%
Reduced aero drag	+1.2	+6.2%	-5.8%
All, combined (actual)	+7.3	+37.6%	-27.4%
(calculated, sum)	+7.3	+37.6%	-34.3%
(calculated, product)	+8.4	+43.2%	-30.2%

Again, use of the power equation, this time with $\phi = 1-0.050\ \ln(N)$, adjusts the product-calculated improvements to the correct values:

$$\frac{MPG_9}{MPG_0} = (1.432)^{1-.050\ \ln(9)} = 1.377, \quad \Delta = +37.7\%$$

from the fuel economy slip product;

$$\frac{MPG_9}{MPG_0} = (0.698)^{1-.050\ \ln(9)} = 0.726, \quad \Delta = -27.4\%$$

from the fuel consumption slip product.

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[228] Porter, "Design for Fuel Economy - The New GM Front Drive Cars", SAE Paper 790721, June 1979.

Based on these two examples, both of which deal with fuel economy improvements, the relation

$$S_N = \left(\prod_{i=1}^{n} s_i \right)^{\phi} \qquad [\phi = 1-0.05 \ln N]$$

produces acceptably accurate estimates of the combined effects, S_N, of N individually-measured slip factors, s_i. The individual and combined slip factors can be either fuel economy or fuel consumption slip factors.

Where some or all of the individual slips represent fuel economy degradations rather than improvements, the equation above is not necessarily accurate, but should provide a better combined-effects estimate than the simple product of the slip factors.

V. FOR THE FUEL DEMAND ANALYST

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V. FOR THE FUEL DEMAND ANALYST

A. The Past Revisited

Since 1972, analyses of EPA fuel economy trends have been published annually in the technical literature, in the form of EPA reports[229] or SAE papers by EPA authors[230-235]. Whether taken at face value or "discounted", the average EPA numbers have come to be widely used as a jumping-off point for fuel demand computations. This report provides a basis for assigning average Road MPG values to each model year, as a function of their EPA averages. In Section III, relationships between road and EPA MPG were developed for model years 1974 through 1979, based on raw data for consumer-driven and fleet cars, known distributions of consumer and fleet VMT, and odometer mileage effects. These data provide a straightforward means of labeling the 1974-79 cars with a Road MPG value.

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[229] U.S. Environmental Protection Agency, "Fuel Economy and Emission Control", November 1972.

[230] Austin and Hellman, "Passenger Car Fuel Economy - Trends and Influencing Factors", SAE Paper 730790, September 1973.

[231] Austin and Hellman, "Fuel Economy of the 1975 Models", SAE Paper 740970, October 1974.

[232] Austin, et al, "Passenger Car Fuel Economy Trends Through 1976", SAE Paper 750957, October 1975.

[233] Murrell, et al, "Light-Duty Automotive Fuel Economy Trends Through 1977", SAE Paper 760795, October 1976.

[234] Murrell, "Light-Duty Automotive Fuel Economy ... Trends Through 1978", SAE Paper 780036, February 1978.

[235] Murrell, "Light-Duty Automotive Fuel Economy ... Trends Through 1979", SAE Paper 790225, February 1979.

In the absence of EPA vs. Road MPG relations for pre-1974 cars, we must note that (1) those cars are in most respects technologically similar to the 1974's, but different from later models, and (2) their average EPA fuel economy is very near that of the 1974's, but different from that of later models. Accordingly, we have applied [only] the 1974 relationship to pre-1974 models. The following table lists the average EPA MPG values and the corresponding Road MPG's, determined on the above basis:

Estimated Average New-Car Fuel Economy at
4000 Miles, by Model Year

	EPA Fuel Economy:				Road Difference:	
Model Year	72 FTP City	75 FTP City	55/45	Road MPG	vs. 75 City	vs. 55/45
pre-1968	12.22	12.88	14.90	13.66	+6.1%	-8.3%
1968	11.89	12.59	14.69	13.53	+7.5%	-7.9%
1969	11.98	12.60	14.74	13.56	+7.6%	-8.0%
1970	11.89	12.59	14.85	13.63	+8.3%	-8.2%
1971	11.67	12.27	14.37	13.33	+8.6%	-7.2%
1972	11.56	12.15	14.48	13.40	+10.3%	-7.5%
1973	11.47	12.01	14.15	13.19	+9.8%	-6.8%
1974	11.51	12.03	14.21	13.23	+10.0%	-6.9%
1975	--	13.69	15.79	13.83	+1.0%	-12.4%
1976	--	15.23	17.46	14.11	-7.4%	-19.2%
1977	--	15.99	18.31	14.72	-7.9%	-19.6%
1978	--	16.97	19.57	15.81	-6.8%	-19.2%
1979	--	17.60	20.11	16.87	-4.1%	-16.1%

B. The Future

That was the easy part. Forecasts of the EPA and Road fuel economy averages for future model years require additional consideration.

First, it is not realistic to expect that the EPA average MPG for a given model year will be exactly equal to the MPG standard for that year. Several manufacturers are today above even the 1985 standard, and few manufacturers will be below a given year's standard if they can help it. The track record for the first three years in which the standards have been in effect shows overall average EPA MPG leading the standard by more than 1 MPG; we assume that this will continue, although by a gradually-decreasing margin:

EPA MPG versus MPG Standards

	Standard	EPA MPG	Difference	
1978	18.0	19.6	+1.6	
1979	19.0	20.1	+1.1	
1980	20.0	22.4	+2.4	Actual
1981	22.0	24.0	+2.0	Estimated
1982	24.0	25.5	+1.5	
1983	26.0	27.0	+1.0	
1984	27.0	27.5	+0.5	
1985	27.5	28.0	+0.5	

Second, while the 1975-79 models may be considered representative of some of the cars of the 1980's from the standpoint of technological similarity, the 1974's are clearly a different breed of hardware. Just as it was our judgement earlier that data from the 1974's is appropriate for pre-1974 cars, 1974 data is simply not technologically appropriate for post-1980 forecasting, whether or not the 1974 data might happen to appear mathematically similar to data from the 1975-79 models.

Another technological consideration applies specifically to the 1975 and 1976 models. As noted in Section IV.B.4.b., significant shortfalls occurred for these two (and only these two) model years at the basic production hardware level. We note that 1975 marked the adoption of new emission control technology, and must allow for the possibility that this change--not the technology itself but its sudden introduction--may have had a negative effect which took two years to dissipate. The phasing-in of technology improvements has since proceeded at a more gradual, evolutionary pace, as evidenced by the lack of similar production slippages for 1977-78-79; we expect that orderly influx of improvements to continue in the 1980's, and there is no basis to project recurrence of the 1975-76 kind of production slip anomaly. Hence when using the 1975-76 EPA vs. Road relationships as (partial) predictors of the future, we have removed the 7-8% production slips that were part and parcel of these models' overall slips. In a similar vein, we have (as is only fair) *discounted* the production slip *overages* observed in the 1977-79 models' data.

Thirdly, from a strictly numerical standpoint, not every model year's data deserves equal weighting when combined with other years' data. Given two data sets, one averaging 15 MPG and the other 25 MPG, the first set is a better predictor in the neighborhood of--say, 18 MPG, while the second set is more reliable when considering what might happen at 27 MPG. In combining the 1975-79 data, we have chosen the weighting parameter:

$$W_{x,i} = \left(1 - \frac{[\,MPG_x - MPG_i\,]}{MPG_x}\right)^2$$

where: MPG_x = EPA MPG being forecasted;
MPG_i = Average EPA MPG for year i; and
[ ] = absolute value.

Thus, if forecasting at 24 EPA MPG, road data from a 12 EPA MPG fleet is weighted by $(.50)^2 = .250$, while road data from a 23 EPA MPG fleet is weighted $(.96)^2 = .920$. Many analyses, including DOE's, throw out data that varies from the value in question by more than 50%; our weighting method does not go that far, but does recognize the need to soften the influence of off-center data. The next table illustrates relative weightings based on each year's average EPA MPG presented earlier.

Weighting Factors for Use of Historical Fuel Economy Data in Forecasting, at Selected EPA MPG Levels

	EPA = 12	16	20	24	27.5
1975 data	.468	.974	.623	.433	.330
1976	.297	.826	.762	.529	.403
1977	.225	.732	.838	.582	.443
1978	.136	.604	.957	.665	.506
1979	.105	.552	.989	.702	.535

Finally, a portion of the road MPG shortfalls for the 1975-1978 models has been attributed to certain inaccuracies in the EPA test procedures for those models, such as imprecise simulation of the tire-to-dyno roll interface and nonuniform distribution of vehicle weights within the EPA weight classes (Section IV.C.). These problems have been reduced or eliminated beginning with model year 1979, and the fuel economy shortfalls due to these factors, are not projected to occur in post-1978 vehicles. Hence the nominal 2.8% shortfall due to these factors has been removed from the 1975-78 data for forecasting purposes, i.e., the projected future MPG performance of vehicles similar to the 1975-78 models has been purged of some road shortfalls where the cause of these types of shortfalls in past models is known to be corrected.

Application of all of the above leads to the following MPG estimates:

Estimated MPG for 1980-85 Vehicles with Technology Similar to 1975-79 Cars, at 4000 Odometer Miles

	MPG Standard	EPA MPG	Road MPG
1980	20.0	22.4	18.1
1981	22.0	24.0	19.0
1982	24.0	25.5	19.8
1983	26.0	27.0	20.6
1984	27.0	27.5	20.8
1985	27.5	28.0	21.1

Note that these estimates apply to vehicles with a late-1970's mix of technologies. The 1975-79 vehicle sample which generated the input data consists mainly of gasoline engines with oxidation catalyst emission control.

As noted earlier in this report, there is evidence that newer technologies may reduce vehicle sensitivity to some real-world conditions. One such technology for which road MPG has been analyzed in some detail is the Diesel; DOE[236] reports an EPA-to-Road relationship for Diesel cars as follows:

$$\text{Road GPM} = 1.17 \times \text{EPA GPM} - .001$$

This equation indicates a road shortfall of about 12% for Diesels, compared to the 22% to 26% shortfalls in the preceding table for 1975-79 type vehicles.

The penetration of Diesels into the vehicle population can be estimated from the trend of Diesel sales fractions in recent model years. In examining these trends we note the Diesel fraction in the California fleet to be a good one-year precursor of the Diesel fraction for the 49-states fleet. With these trend data and the "Pearl equation" frequently used in forecasting,

$$y = \frac{1}{a + be^{-cx}}$$

a Diesel fraction of 14% is projected for 1985. The historical data and the fitted Pearl curve are shown in the next figure; the "GM projections" shown are from a trade journal in the public domain[237], and--although not used to construct the Pearl curve--are in good agreement with it.

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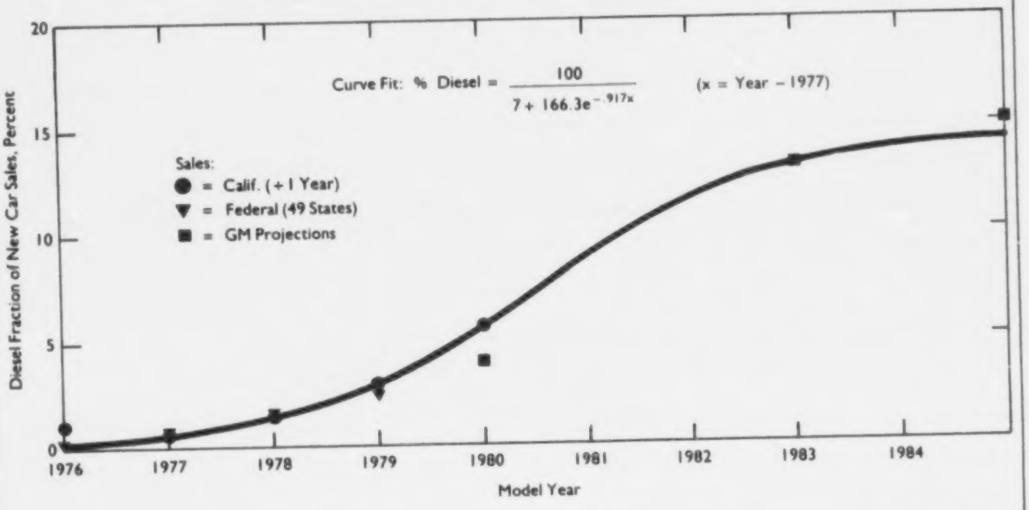
[236] McNutt, Dulla and McAdams, "Comparison of EPA and In-Use Fuel Economy of 1974-1978 Automobiles", Internal DOE Report, October 1979.

[237] Automotive News, June 4, 1979.

FIGURE 66. Estimated Diesel Fraction of New Car Sales vs. Year



Of the many other technology alternates expected to see gradually increased usage in the 1980's, the only other one for which there is any appreciable road data is that of front-wheel drive cars.

Our analysis of GM's 1975 customer survey data shows total road slips as follows for Eldorado and Toronado front drive cars and their most closely-matched rear drive counterparts.

MPG Slip Factor, Road/EPA City

	Front Drive	Rear Drive
Cadillac	1.02	1.00
Oldsmobile	1.07	1.02

This indicates a road MPG advantage of 2% to 5% for the GM front drive models. Road MPG for Ford's 1978 Fiesta front drive car has been reported[238] to be 2.3% above the overall Ford MPG regression curve while that of the nearest rear drive competitors (Pinto/Bobcat and Mustang II) was 0.3% below the curve, implying a net 2.6% road advantage for the front drive model. These GM and Ford data together show an average front drive road advantage of 3.2%. As to market penetration, GM is quoted[239] as estimating a front drive sales fraction of 50% for their car lines by the mid-1980's.

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[238] South and Raja, "In-Service Fuel Economy", SAE Paper 790227, February 1979.

We have not analyzed any of the other new technologies in any detail, for forecasting purposes; because of this, and because there is some uncertainty as to the buildup rates for Diesels and front drives, we have estimated improved technology impacts on the 1980-85 fleets in terms of two scenarios which we believe constitute upper and lower bounds, in fuel economy terms, to what will transpire in the next six years. The lower bound, Scenario "A", assumes market penetrations by 1985 of 14% for Diesels and 25% for front-drive cars; the upper bound, Scenario "B", assumes 20% and 50% respectively for Diesels and front drives. The forecasts for these scenarios are given in the next table.

The pre-1985 market fraction buildups for these cases are also hypothetical; the gasoline cars' and Diesel cars' respective EPA MPG values are determined from these market penetrations and assumed overall EPA MPG values presented earlier. The estimated Diesel fleet MPG's for each year reflect consideration of sales shifts between the manufacturers of Diesel cars.

By 1985, the effect of expanded use of these improved technologies increases fleet road MPG over the "late 1970's technology" figures presented earlier, by 0.7 MPG--for Scenario A, to 0.9 MPG--for Scenario B.

The road shortfalls implied by these figures are given in the table following, using three reference values to define "shortfall": The EPA 55/45 value, the MPG Standard, and lastly-the EPA City MPG value. Evaluation of the latter is important in view of the [interim] use of only the City numbers in current Fuel Economy Labels and Gas Mileage Guides.

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[239] Ward's Engine Update, June 8, 1979.

Forecasts of 4000-mile MPG for two Improved-Technology Scenarios

	% of vehicles:		EPA MPG:		Road MPG:
	FWD	Diesel	Gasoline	Diesel	(all cars)
Scenario "A": 1985 fleet 14% Diesel, gasoline cars 25% front wheel drive					
1980	5	6	22.1	28.6	18.4
1981	8	9	23.6	28.5	19.5
1982	13	12	25.2	28.5	20.3
1983	17	13	26.7	29.0	21.2
1984	20	14	27.2	29.5	21.5
1985	21	14	27.7	30.0	21.8
Scenario "B": 1985 fleet 20% Diesel, gasoline cars 50% front wheel drive					
1980	6	6	22.1	28.6	18.4
1981	13	11	23.6	28.4	19.5
1982	23	15	25.1	28.3	20.4
1983	31	18	26.6	28.8	21.3
1984	38	19	27.1	29.4	21.6
1985	40	20	27.6	29.9	22.0

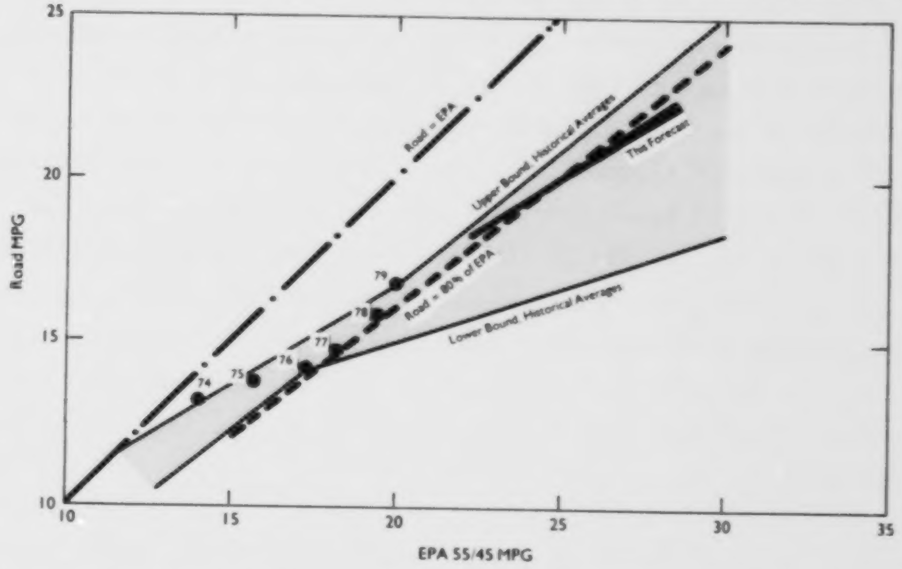
Road MPG Shortfalls for the Two Scenarios, at 4000 Miles

	versus EPA 55/45 MPG:		versus MPG Standard:		versus EPA City MPG:	
	A	B	A	B	A	B
1980	4.0(18%)	4.0(18%)	1.6(8%)	1.6(8%)	0.9(5%)	0.9(5%)
1981	4.5(18%)	4.5(19%)	2.5(11%)	2.5(11%)	1.2(6%)	1.2(6%)
1982	5.2(20%	5.1(20%)	3.7(15%)	3.6(15%)	2.0(9%)	1.9(9%)
1983	5.8(21%)	5.7(21%)	4.8(18%)	4.7(18%)	2.4(10%)	2.3(10%
1984	6.0(22%)	5.9(21%)	5.5(20%)	5.4(20%)	2.6(11%)	2.5(10%)
1985	6.2(22%)	6.0(21%)	5.7(21%)	5.5(20%)	2.7(11%)	2.5(10%)

Since shortfalls are projected with respect to the City values, the interim City-only system may not be acceptable as a permanent arrangement for the EPA/DOE Fuel Economy Information program.

The historical and forecasted fleet road MPG values from all of the analyses above are shown on the familiar "road vs. EPA" plot in the next figure. The boundary curves for the historical data (see Section III) are also shown. The forecasted band is seen to be within those boundaries, and very near the line of a constant 20% shortfall.

FIGURE 67. Relations Between Road and EPA Fuel Economy, Historical and Forecasted



It is of interest to estimate the MPG Standards which correspond to specific road fuel economy levels. Such estimates necessarily involve some extrapolation; nevertheless, the next table presents such estimates for the two 1980's scenarios, and also for the "1975-79 technology" case described earlier.

MPG Standards for Selected
Road MPG Values, at 4000 Miles

Road MPG	1975-79 Technology	Scenario "A"	Scenario "B"
22	30	28	28
24	35	33	32
26	41	37	36
27.5	45	41	39
30	51	47	44

C. Vehicle Age Effect

It has been emphasized that all of the foregoing applies to vehicles at odometer mileages of 4000 miles. We have done that because, for trend analysis and fuel demand forecasting, it must be recognized that the fuel economy of a given model year's fleet is not a time-invariant constant. The 1973 models' average road MPG in 1973 was one value, in 1978 another value, and in 1984 it will be yet another. Since vehicle fuel economy is determined in large measure by how the vehicles are driven, no analysis can produce a number guaranteed to occur. However, certain aspects of vehicle behavior which affect fuel economy are known to vary with odometer mileage, and do permit some estimate of time variations in average MPG.

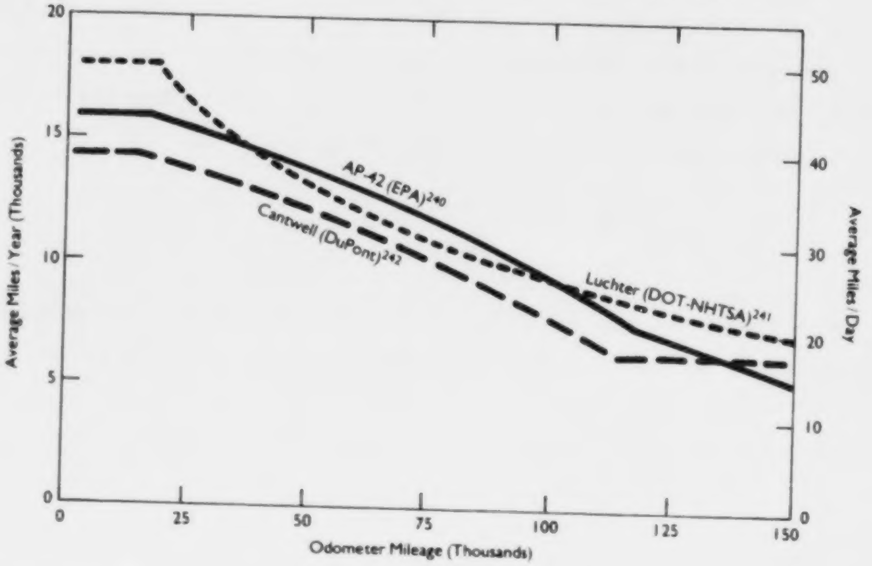
Section III.C.3. presented an equation relating odometer mileage to MPG:

$$\frac{MPG}{MPG_{4K}} = 0.0186\ \ln(ODO) + 0.846 \qquad [\text{ODO = odometer mileage}]$$

This relationship indicates an initially steep, and later more gradual, rise in MPG with mileage accumulation under constant operating conditions.

But it is well known that vehicles are not used exactly the same way throughout their lifetimes. The next figure illustrates patterns of decreasing annual miles traveled, from three of many models in current use in demand forecasting[240-242]. This has a definite fuel economy

FIGURE 68. Decreasing Vehicle Travel with Vehicle Age



effect, as discussed in Section IV.C.2,d. The applicable relationship is:

$$\frac{MPG}{MPG_{41.1}} = 0.125\ \ln(AMPD) + 0.535 \qquad |\text{AMPD = Avg. miles/day}|$$

or its equivalent,

$$\frac{MPG}{MPG_{15K}} = 0.125\ \ln(AMPY) - 0.202 \qquad |\text{AMPY = Avg. miles/year}|$$

(The fact that the equations fall apart below 5.0 miles driven per year, or 73 feet per day, is of no practical significance.)

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[240] U.S. Environmental Protection Agency, "Mobile Source Emission Factors", Report EPA-400/9-78-005, March 1978.

[241] Luchter, "The Methodology of Passenger Automobile Fuel Economy Rulemaking-Part 1: Technology", SAE Paper 790380, March 1979.

[242] Cantwell _et al_, "Projections of Motor Vehicle Fuel Demand and Emissions", SAE Paper 780933, November 1978.

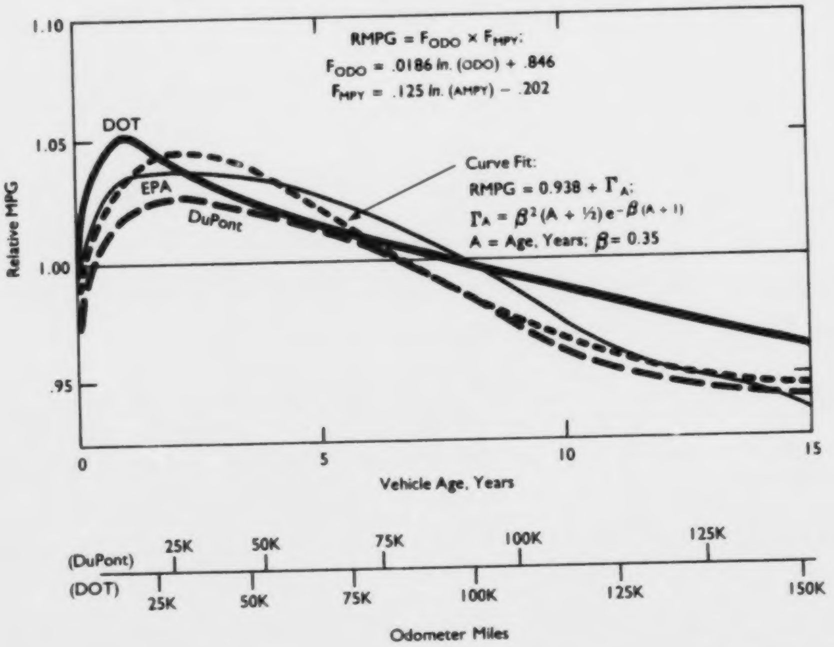
When combined, the ODO and AMPY relationships provide an estimate of relative fuel economy as a function of vehicle age, for a given annual mileage trend model. The resulting time histories of relative MPG for the three cases from the preceding figure are shown in the next figure. In all cases, relative MPG rises initially, reaches its peak in one to two years, and declines thereafter. This general behavior can be reasonably well represented by use of a function of the form

$$f(A) = \beta^2 A_1 e^{-\beta A_2}$$

where A = vehicle age and A_1 and A_2 are functions of A. The equation for relative MPG using this function, as shown on the figure, is:

$$Relative\ MPG = 0.938 + \beta^2 (A+1/2) e^{-\beta(A+1)} \quad [\beta = 0.35]$$

FIGURE 69. Relative Fuel Economy vs. Vehicle Age



VI. CONSUMER ADJUSTMENT OF EPA MPG

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VI. CONSUMER ADJUSTMENT OF EPA MPG

As recognized by the Conference Committee for NECPA 1978 (See Section I), it would be desirable to devise a practicable approach with which individual consumers could "adjust" the EPA MPG figures to reflect the particulars of their own vehicle usage situations.

EPA and others have been exploring such adjustment methods for a number of years. This section discusses the more promising of these approaches. As a result of these studies, we are not optimistic as to the development of an adjustment method that is acceptably accurate, and at the same time acceptably simple for consumer use.

A. Questionnaire Approach

Ten factors, known to influence vehicle fuel economy and reasonably well-quantified in the technical literature, were incorporated into a questionnaire by means of which individual drivers can characterize their own driving conditions. By totalling point values assigned to each individual answer, a respondent arrives at a total score which, via a look-up table, is used to adjust the EPA MPG value upward or downward in accordance with the respondent's own "driving profile". Each individual answer score is scaled logarithmically to the fuel economy adjustment coefficient for that condition, and the total score is proportional to the sum of all of the answers' logarithms: this has the same effect as multiplication of the individual adjustment coefficients, and the total score is thus related to the product of the individual factors, a "net adjustment factor", as it were. For a given EPA fuel economy value and total score, the look-up table gives the adjusted MPG corresponding to this net adjustment factor.

The questionnaire and look-up table are shown below. It will be noted that a total score of 26 corresponds to no adjustment of the EPA value. Those questionnaire answers which describe the EPA combined City-Highway test conditions do in fact produce a total score of 26, but other combinations of answers which also yield this score also result in no net adjustment of the EPA MPG value.

The scoresheet below permits you to see how your own "driving profile" affects your gas mileage. For example, you can calculate the gas mileage you would get on a summer vacation trip and compare that with your calculated fuel economy for winter home-to-work commuting.

To fill out the scoresheet, pick the single most appropriate answer for each question and enter the score for that answer in the space provided. If two answers are equally appropriate, enter the average of the two point values. After entering scores for all the questions, total your score, find your car in the booklet, and note its listed EPA combined City/Highway fuel economy: ________. Use the mileage scoring table to determine the adjusted gas mileage value for your driving profile.

In addition, you can use the scoresheet to help explain actual measurements you make of your car's gas mileage. When you use the scoresheet this way, answer the questions according to the way the car was driven between the last two tankfills you used for your measurement.

1. WHAT IS THE OUTSIDE TEMPERATURE FOR MOST OF YOUR DRIVING?

OVER 40°F (1)

UNDER 40°F (0)

____
POINTS

2. WHICH OF THE FOLLOWING BEST DESCRIBES THE ROAD SURFACE YOU DO MOST OF YOUR DRIVING ON?

SMOOTH PAVEMENT (4)

BROKEN PAVEMENT OR PACKED DIRT/GRAVEL (2)

LOOSE GRAVEL OR DIRT (0)

____
POINTS

3. SELECT THE CATEGORY THAT BEST DESCRIBES THE TERRAIN IN WHICH YOU DRIVE:

FLAT OR GENTLY ROLLING (3)

HILLY (2)

MOUNTAINOUS (0)

____
POINTS

4. WHAT IS THE OVERALL AVERAGE SPEED FOR YOUR TRAVEL? (REMEMBER, THE AVERAGE SPEED OF A TRIP IS ALWAYS LESS THAN YOUR CRUISING SPEED)

UNDER 17 MPH (0)

17-24 MPH (1)

25-33 MPH (2)

34-50 MPH (3)

51-65 MPH (2)

OVER 65 MPH (1)

____
POINTS

5. WHICH CATEGORY BEST DESCRIBES THE NATURE OF THE TRAFFIC FLOW YOU ENCOUNTER?

CRUISE OR NONSTOP (4)

ESPECIALLY FREE-FLOWING (3)

ABOUT AVERAGE FOR ROAD TYPE (2)

UNUSUALLY CONGESTED (1)

______ POINTS

6. SELECT THE TYPE OF ACCELERATIONS YOU NORMALLY USE WHEN DRIVING:

SMOOTH AND GRADUAL (2)

ABOUT AVERAGE (1)

RAPID (0)

______ POINTS

7. DO YOU OPERATE YOUR AIR CONDITIONER MOST OF THE TIME?

NO (3)

YES (2)

______ POINTS

8. FROM THE TOP ROW, SELECT YOUR AVERAGE TRIP DISTANCE; THEN FROM THE VERTICAL COLUMN SELECT THE PERCENTAGE OF YOUR TRIPS WHICH ARE MADE FROM A COLD START. (COLD START MEANS THE ENGINE HAS BEEN OFF FOR AT LEAST FOUR HOURS.) PICK THE SINGLE MOST APPROPRIATE POINT VALUE.

	0-5 MILES	5-10 MILES	OVER 10 MILES
25% COLD STARTS OR LESS	(3)	(3)	(3)
25-50% COLD STARTS	(2)	(3)	(3)
OVER 50% COLD STARTS	(0)	(2)	(3)

______ POINTS

9. DO YOU KEEP YOUR CAR MECHANICALLY MAINTAINED (AND ENGINE TUNED) ACCORDING TO THE MANUFACTURER'S SPECIFICATIONS?

YES (3)

NO (2)

______ POINTS

10. WHICH OF THE FOLLOWING CATEGORIES BEST DESCRIBES THE LOAD YOU NORMALLY CARRY?

1 or 2 OCCUPANTS (4)

3 or MORE OCCUPANTS (3)

1,000-2,000 lb CARGO OR TRAILER (2)

2,000-3,000 lb CARGO OR TRAILER (1)

CARGO OR TRAILER OVER 3,000 lb (0)

______ POINTS

______ VEHICLE CODE NO.	______ YOUR MEASURED GAS MILEAGE	______ YOUR ZIP CODE	______ TOTAL POINTS

Gas Mileage Scoring Table

Fuel Economy listed in Gas Mileage Guide (Combined City/Highway) :

Total Points	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	26	28	30	32	34	36
	Your ADJUSTED Fuel Economy:																				
17	4	4	5	5	6	6	7	7	7	8	8	9	9	10	10	11	12	12	13	14	15
18	4	5	5	6	6	7	7	8	8	8	9	9	10	10	11	12	12	13	14	15	16
19	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12	13	14	15	16	17	18
20	6	7	7	8	9	9	10	10	11	12	12	13	13	14	15	16	18	18	20	21	22
21	7	7	8	8	9	10	10	11	12	12	13	14	14	15	16	17	18	20	21	22	24
22	7	8	8	9	10	11	11	12	13	13	14	15	16	16	17	18	20	21	23	24	25
23	8	8	9	10	11	11	12	13	14	14	15	16	17	18	18	20	21	23	24	26	27
24	8	9	10	11	12	12	13	14	15	16	16	17	18	19	20	21	23	25	26	28	30
25	9	10	11	12	13	14	14	15	16	17	18	19	20	21	22	24	25	27	29	31	33
26	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	26	28	30	32	34	36
27	11	12	13	14	16	17	18	19	20	21	22	23	24	25	26	29	31	33	35	38	40
28	12	13	15	16	17	18	20	21	22	23	24	26	27	28	30	32	34	37	40	42	44
29	13	15	16	18	19	20	22	23	24	26	27	28	30	31	32	35	38	40	43	46	49
30	15	16	18	20	21	22	24	25	27	28	30	31	33	34	36	39	42	45	48	51	54

The questionnaire was subjected to three field trials, whose results are summarized in the table below. For each of the trials, the table shows the ratio of in-use road MPG to EPA MPG, averaged over all respondents, and the range and coefficient of variation (standard deviation divided by the average) for this ratio. The right side of the table shows the same types of figures for the ratio of adjusted MPG to road MPG. Ideally -- if the questionnaire adjustment was highly successful -- the latter ratio should average very near 1.00, the range of ratios should be very narrow, e.g. 0.98-1.02, and the coefficient of variation should be significantly reduced, which would indicate that the adjustments produced nearly exact matches to each respondent's road MPG experience.

Results of Fuel Economy Questionnaire Trials

	Road MPG/EPA MPG:			Adjusted MPG/Road MPG:		
Trial	Average	Range	C.O.V.	Average	Range	C.O.V.
EPA	0.80	0.75-0.86	7%	0.71	0.58-0.75	14%
Ford	0.90	0.68-1.28	18%	1.00	0.70-1.30	21%
GSA	0.93	0.63-1.17	16%	1.12	0.94-1.59	16%

In the EPA trial, a number of employees of the EPA's Ann Arbor, Michigan laboratory worked with a preliminary version of the questionnaire; this trial resulted in a general downward overcorrection and an increase in scatter for the adjusted values. The questionnaire and look-up table were modified somewhat as a result of the EPA trial, and the modified version (which is the one illustrated earlier) was used in trials by Ford Motor Company employees in Dearborn, Michigan and GSA employees in Washington, D.C. The Ford trial gave excellent average agreement between adjusted MPG's and road MPG's, but the adjustment again increased the dispersion on a driver-by-driver basis. In the GSA trial, the adjustment overestimated road MPG; i.e., did not (on the average) bring the EPA values down enough to match actual road MPG. As in the other trials, the adjustment scheme in the GSA trial did nothing to reduce dispersion. It must be concluded that this questionnaire is of only marginal value in adjusting EPA MPG values *on the average* to match real experience, and of no value at all in producing adjusted EPA MPG values which better match *individual drivers'* actual fuel economy.

In our post-mortem on this adjustment scheme, we find, to be sure, certain detailed shortcomings in this particular questionnaire; the location of cutpoints between one answer/score combination and the next, omission of additional factors such as odometer mileage, tire pressure, and the like. But more importantly, we find that this general *approach* to individual driver fuel economy adjustment has a *fundamental deficiency:* there is in any questionnaire approach an inevitable trade-off between accuracy and simplicity. There is little doubt that expansion of the above questionnaire to cover 15, or 20, or 30 influences would improve its driver-to-driver MPG accuracy, as would expansion of the number of possible answers to the individual questions. Additional complication in the latter vein would certainly reduce problems of gross digitization, such as an average speed of 51 mph yielding a 10% MPG difference from 50 mph. However, even the existing questionnaire may be near, or possibly beyond, that limit of complexity at which consumer acceptance and use become extremely unlikely.

B. Adjustment Formula Approaches

EPA analysis of the 1975 GM customer survey data base produced the following four-factor MPG equation:

$$\frac{\textit{Actual MPG}}{\textit{EPA City MPG}} = .1268(\ln AMPD) -.0118(\ln POP) +.00123(T) -.00055(RH) +.6570$$

where AMPD = Average miles driven per day
POP = Population of owner's ZIP code
T = Temperature, °F
RH = Relative humidity, percent
ln = Natural logarithm

The correlation coefficient is 0.620 and the standard error is 0.123.

If AMPD, POP, T, and RH are known, an adjusted MPG ratio corresponding to those four factors can be computed from the equation. For a given vehicle, multiplication of the vehicle's EPA City MPG by this MPG ratio, or factor, gives an adjusted MPG which should approximate the fuel economy that particular driver should expect on the road.

If a consumer knows the EPA City figure for his car, the other four input variables are readily available, and his adjusted MPG can be arrived at graphically by means of the next chart. In the example on the chart, a car with an EPA City rating of 26 MPG, in a location with a population of 150,000, is driven 60 miles/day, at 30°F and 30% relative humidity: the chart predicts a road fuel economy of 27 MPG under these conditions.

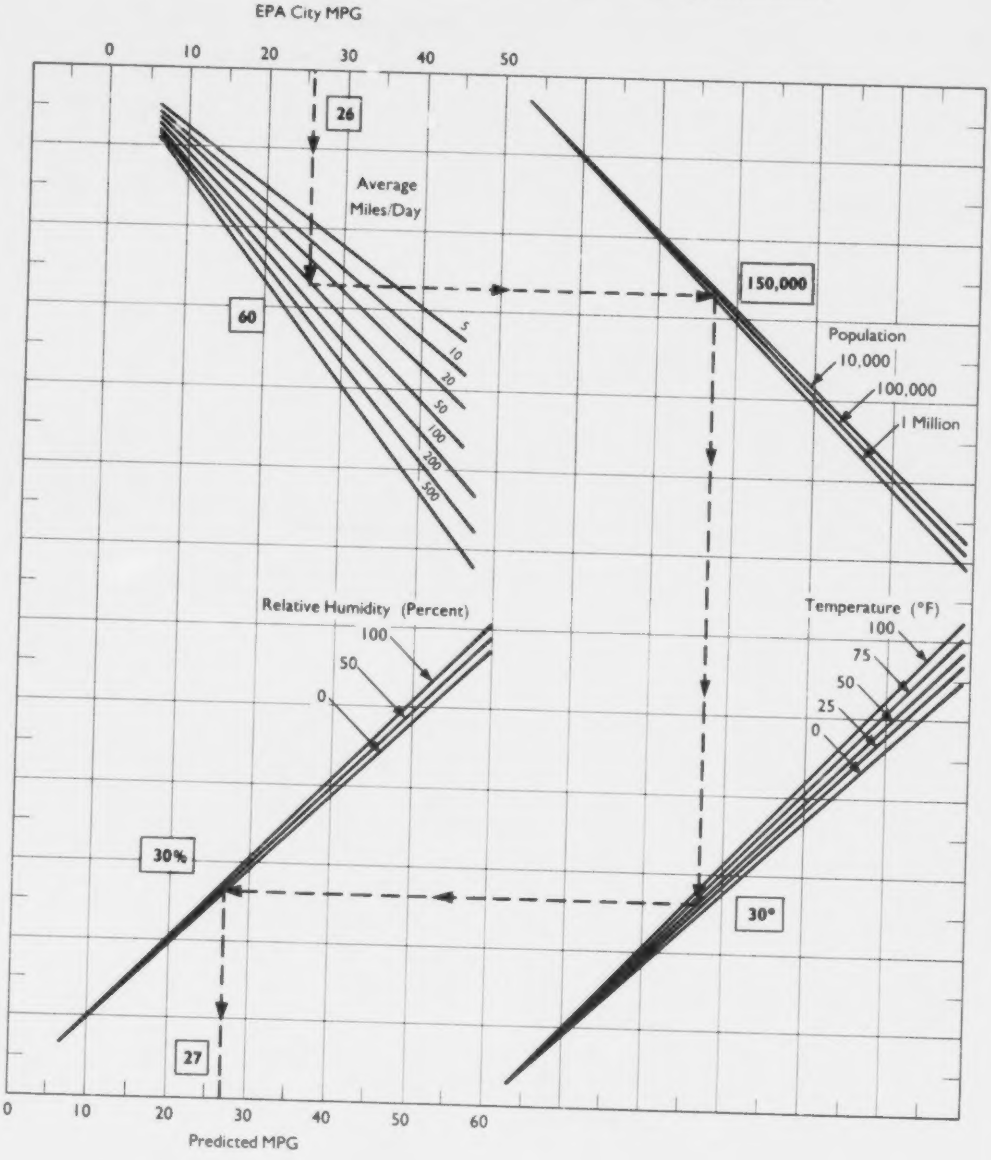
This adjustment scheme was tested by playing it back through the GM data base, using the four-factor equation and the specific conditions for each car, to calculate individual adjusted MPG values. As with the questionnaire approach, the averages, ranges and coefficients of variation were determined for the aggregate road-to-EPA MPG ratio; again, the adjustment would be considered successful if the latter ratio averaged 1.00 and showed a significantly smaller range and C.O.V. than the unadjusted data. The results of this test are summarized below.

Results of Test of Regression Equation Adjustment

	Average	Range	C.O.V.
Road MPG/EPA 55/45 MPG	0.8745	0.42-1.45	15.4%
Adjusted MPG/Road MPG	0.9999	0.71-1.40	9.7%

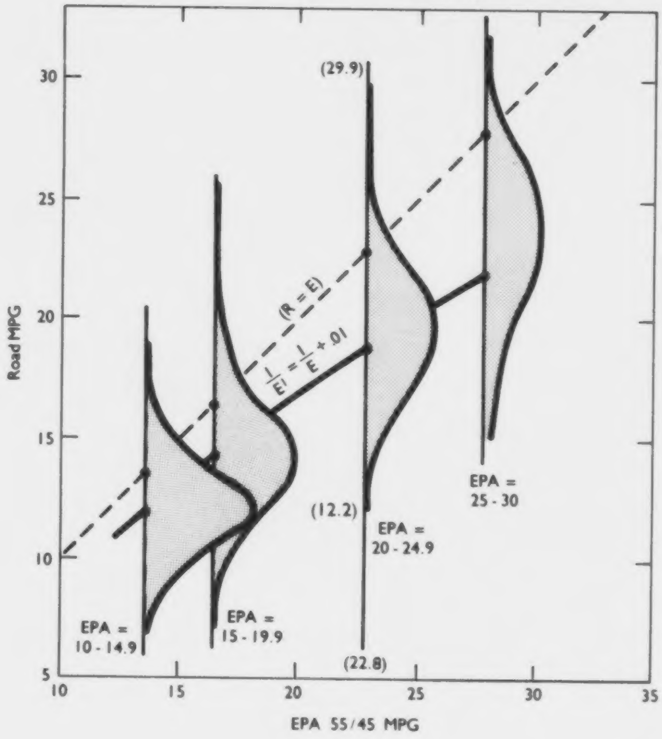
On the average, this adjustment performed quite well, but it had a relatively minor impact on the dispersions. With a coefficient of variation of 10% and individual variations as high as 40%, it is clear that many individual drivers would have benefited little from this method of adjustment.

FIGURE 70. Construction Plot for Fuel Economy Adjustment



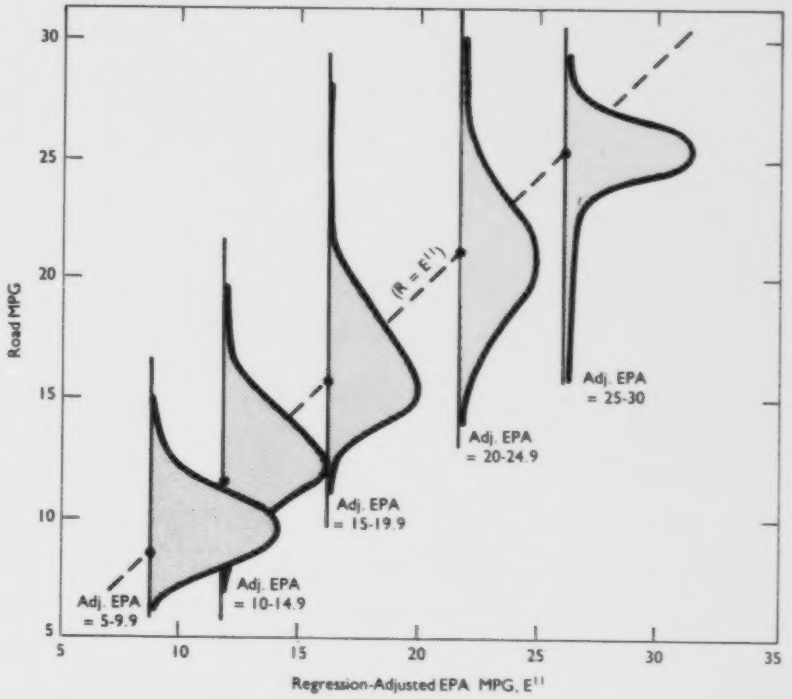
This is depicted quite clearly in the next two figures. The first figure shows the distribution of road MPG's for four "EPA MPG" strata of the GM data. Each stratum includes all cars whose EPA MPG falls within a 5-MPG band. For the 20-24.9 MPG stratum, for example, average EPA MPG is 22.8, and road MPG for these cars ranges from a minimum of 12.2 to a maximum of 29.9; the peak of the distribution of road MPG's for this stratum is at 19.9 MPG, and the average road MPG is 19.2. It is obvious from this figure that most cars' road MPG's are below their EPA value, although a small minority of cars did achieve or surpass their EPA numbers. In this figure, the peaks of the road MPG distributions coincide reasonably well with a simple adjustment of the EPA values proposed by General Motors: $1/R = 1/E + .01$

FIGURE 71. Distributions of Road Fuel Economy
(1975 GM Customer Survey)



In the second figure, the regression-adjusted EPA values now coincide with the peaks of the road MPG distributions, indicating good agreement between average road MPG and the regression-adjusted EPA figures, but the scatter in road MPG for a given adjusted EPA MPG is still significant.

FIGURE 72. Distributions of Road Fuel Economy with Respect to "Adjusted EPA MPG"
(1975 GM Customer Survey)



For further illustration, the data for a randomly selected group of ten identical vehicles from the GM data base are shown in the following table. The table shows actual fuel economies and actual-to-EPA City MPG ratios, the four factors used in the regression equation adjustment, and the resulting calculated fuel economies and calculated-to-EPA City MPG ratios.

Example of Fuel Economy Adjustment for Ten Identical GM Vehicles
(EPA MPG = 12.3 City, 19.0 Highway, 14.6 Combined)

Car	Actual MPG	Act. MPG / EPA City MPG	Avg. Miles Per Day	Pop (000)	Temp (°F)	RH (%)	Calc. MPG	Calc. MPG / EPA City MPG
A	16.3	1.33	429.0	3.47	46	75	16.5	1.34
B	11.1	.90	17.0	3000	72	71	10.9	.89
C	12.1	.98	50.0	3.71	72	71	13.6	1.11
D	11.5	.93	12.6	747.0	34	88	10.0	.81
E	14.5	1.18	23.8	747.0	34	88	11.0	.89
F	16.1	1.31	45.6	2.34	70	78	13.4	1.09
G	15.2	1.24	38.5	3.31	68	75	13.1	1.07
H	10.3	.84	26.6	13.23	39	68	12.0	.97
I	16.8	1.37	23.4	260.0	72	73	11.8	.96
J	12.4	1.01	6.2	82.50	66	77	9.8	.79

Actual		Calculated
1.11	Average Ratio, $\frac{\text{Road MPG}}{\text{EPA City MPG}}$	0.99
0.20	Standard Deviation	0.16
18%	Coefficient of Variation	17%

In the aggregate, the adjustment resulted in a 12% underestimation of average road MPG for this group of vehicles. Dispersions were not appreciably reduced. For the first two individual cars, the adjusted MPG's agree quite well with the actuals; for the other eight cars, however, adjusted fuel economy differs from the actual by at least 1.5 MPG and as much as 5 MPG.

This example also exposes the possible error of assigning meteorological and demographic data to individual cases based on survey dates and vehicle owners' home ZIP codes: Vehicle A, averaging 429 miles per day during the survey period, was very likely nowhere near home, and the conditions existing in its home ZIP code at that time could have been quite different from those where the car was being operated.

From a fuel economy survey of 1978 model Ford Motor Co. employee lease cars, South[243] reports regression equations as follows:

$$MPG_{summer} = .8232(MH) - 1.331 + .9194x10^{-2}(MPD) - .02528(URBAN) + .2921(lnAM)$$

$$MPG_{winter} = .6875(MH) - 1.118 + 2.093x10^{-2}(MPD) - .02076(URBAN) + .3256(lnAM)$$

$$GPM_{summer} = 1.149(1/MH) + .01102 - .3922x10^{-4}(MPD) + .1067x10^{-3}(URBAN) - .1319x10^{-2}(lnAM)$$

$$GPM_{winter} = 1.294(1/MH) + .01659 - 1.088x10^{-4}(MPD) + .1345x10^{-3}(URBAN) - .2042x10^{-2}(lnAM)$$

where MH = EPA 55/45 MPG
MPD = Average miles driven per day
URBAN = Percent urban driving, driver estimated
lnAM = Natural log of average odometer miles

All correlation coefficients are 0.81 or higher. The first two equations (fuel economy regressions) were used to adjust the raw data values. As with the GM case, the adjustments reduced dispersions but did not eliminate them, as indicated below:

	Summer Data	Winter Data
Unadjusted	C.O.V. = 13.6%	C.O.V. = 14.7%
Adjusted for MPD, URBAN, AM	C.O.V. = 11.3%	C.O.V. = 10.6%

The figure shows road vs. EPA MPG for the raw data and the three-parameter adjusted data. The significant upward movement of the corrected Winter regression line indicates that the Winter operational characteristics were detrimental to fuel economy. The remaining Summer-to-Winter MPG difference is due to factors unaccounted for, the most obvious of which are temperature and road condition; this residual difference is worse for higher-MPG cars (11% Summer-to-Winter shortfall at 30 MPG vs. 6% Summer-Winter shortfall at 15 MPG).

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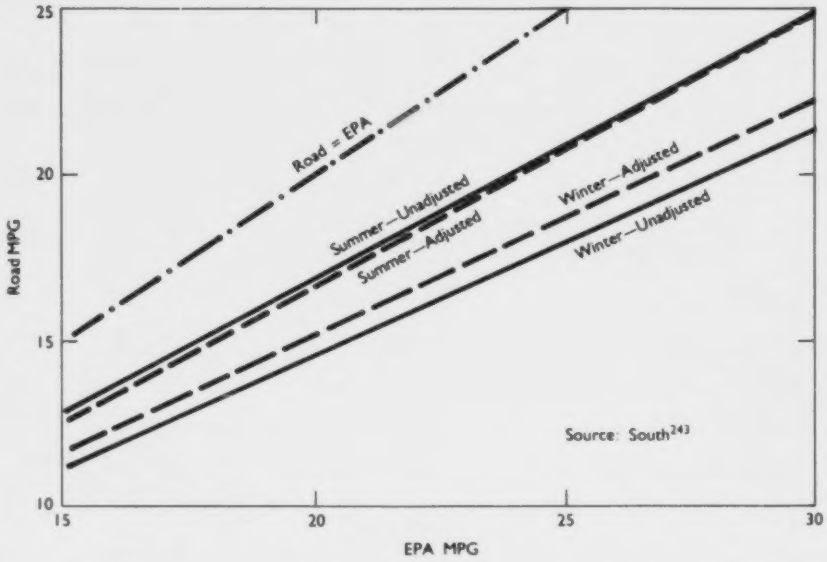
[243] South, "Further Results from the 1978 Fuel Economy Survey", SAE Paper 790931, October 1979.

FIGURE 73. Effects of Usage Parameter Adjustment on In-Use MPG Regression Lines



Source: South[243]

The effects of the adjustment on the summer data for one specific car model (over 300 cars) are shown below.

	Unadjusted	Adjusted
Average MPG	17.32	17.22
Maximum MPG	24.93	21.90
Minimum MPG	12.05	12.94
C.O.V.	11.5%	9.4%

Again, less than half of the C.O.V. was eliminated by the adjustment.

Adjustment of EPA MPG values by means of multi-factor equations such as the above could prove valuable on an average basis; however, this approach is no more acceptable for individual consumers than is the questionnaire approach, principally because of the many fuel economy influences which cannot be represented, and which therefore cannot enter into the adjustment.

VII. PUBLIC COMMENT

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VII. PUBLIC COMMENT

A. Invitation

Notice of opportunity for public comment was published in the Federal Register on July 12, 1979 (44 F.R. 40724). Eleven comments were received as of August 27, 1979, as follows:

Private Citizens

W. Mark Day
M. P. Stombler

Consumer Groups

American Automobile Association
Automobile Club of Southern California

Industrial Concerns

American Motors Corporation
American Oil Company
American Petroleum Institute
Chrysler Corporation
Ford Motor Company
General Motors Corporation
Tosco Corporation

B. Summary of Comments Received During Report Preparation

PRIVATE CITIZENS

- EPA estimates should be made more representative of actual use, to compare present vehicle to potential replacement vehicle;
- Suggestions for changing EPA estimates and procedures:
  - decrease EPA estimates to represent typical engine mistuning and wheel misalignment;
  - decrease temperature for cold-start;
  - use short trips with engine cool-down between trips;
  - refine altitude information given to public;
  - advise people of temperature effects.
- Get rid of the dynamometer;
- EPA should use a steady-state track test which the average driver can relate to (e.g., 55 mph steady cruise);
- Driving his BMW at 70-90 mph, he gets 18 MPG at low altitude and 25 MPG at high altitude.
- Include effects of:
  - aerodynamics;
  - inertia;
  - altitude

AMERICAN AUTOMOBILE ASSOCIATION (AAA)

- EPA test fuel is not representative of pump gasoline, and differences in fuel properties can create road MPG shortfalls.

AMERICAN MOTORS CORPORATION

- Test brake drag is 1/2 of actual;
- Test tire pressure is greater than actual;
- Tire loss is less for test (2 tires versus four);
- 4000 mile EPA test vehicles maintained better than older cars;
- 4000 mile EPA test vehicles are selected to represent mean of production vehicles: more variability in actual vehicles;
- Driver performance must be accounted for.

AMERICAN OIL COMPANY

- Road Fuel Economy Relationships:

Model Year	No. Cars	Equations
1974	1656	$\text{Road MPG} = 1.04\ (\text{EPA MPG})^{.9642}$
1975	2485	$\text{Road MPG} = 2.86\ (\text{EPA MPG})^{.5670}$
1976	2410	$\text{Road MPG} = 2.84\ (\text{EPA MPG})^{.5695}$
1977	2375	$\text{Road MPG} = 1.71\ (\text{EPA MPG})^{.7479}$

AMERICAN PETROLEUM INSTITUTE

- Road MPG for Domestic makes in fleet use:
  - 1968 to 1974, from 83% (1973) to 94% (1968) of 1967 MPG;
  - 1975 to 1977, from 92% (1975) to 103% (1977) of 1967 MPG.
- Road MPG corrected for changes in vehicle design characteristics (not corrected for odometer mileage effects):
  - 1968 to 1974, from 88% (1973) to 99% (1969) of 1967 MPG;
  - 1975 to 1977, from 97% (1975) to 106% (1977) of 1967 MPG.
- Emission controls blamed for MPG losses (not credited for gains)

AUTOMOBILE CLUB OF SOUTHERN CALIFORNIA

- Survey of 1.5 million club members:
  - An increasing number of motorists are aware of the EPA estimates;
  - A significant number of motorists (46%) compare their own fuel economy with the estimates;
  - A majority (51%) indicate that their auto obtained worse fuel economy than the 55/45 estimate.
- Relationship of in-use fuel economy to EPA estimates:
  - mature engines give 7% better fuel economy than green engines;
  - EPA ratings overestimate road MPG by 7% (1976) to 9% (1977);
  - carbon balance fuel measurement underestimates fuel economy by 4% (1977) to 6% (1976).
- Recommended:
  - whole number range (e.g., 13-18 MPG) for future EPA estimates;
  - intensive EPA/DOE data collection, computer analysis, and mathematical modeling of influence factors.

CHRYSLER CORPORATION

- Sees no reason to change EPA's testing procedures: supports EPA's test. Since so many factors affect fuel economy, no single test can be in all ways "representative";
- EPA test is good for measuring relative fuel economy.

FORD MOTOR COMPANY

- Ford's 1979 production cars are fairly represented by their test prototypes;
- Supports the EPA test procedure:
  - simplicity;
  - both emissions and fuel economy are measured at same time;
  - accurate relative MPG comparison;
  - dyno test can be done consistently year-round (not affected by weather, etc.).
- In-use influences penalize smaller cars more than larger ones:
  - trip length and accumulated mileage tend to be less in an urban environment, and smaller cars are found more in that environment;
  - small cars have smaller displacement-to-weight ratios, which results in more carburetor enrichment;
  - payload effect is greater for smaller cars;
  - smaller tires on smaller cars have greater dyno effect.
- Vehicle Condition
  - older cars are driven less, and used less for long trips; are also in worse state of tuning, tire inflation, and wheel alignment;
  - power load from additional accessories is greater in actual vehicles;
  - EPA test does not differentiate properly between bias and radial tires.
- Differences due to Environment
  - wind;
  - grades;
  - temperature.

- Dyno/Road Differences
  - tire cooling is different on road; this causes higher road rolling resistance;
  - road acceleration rates are greater than in the dyno test;
  - inertia simulation is hampered by tire slippage on dyno.

GENERAL MOTORS CORPORATION

- The EPA test was never intended to represent actual fuel economy;
- Estimated EPA fuel economy is useful to public for comparison, as stated on label;
- It is difficult to quantify the fuel economy effects of:
  - road surface
  - state of repair of road
  - road grade, curvature, crown
  - wind
  - precipitation
  - altitude
  - humidity and temperature
  - accessory loads
  - vehicle maintenance
  - vehicle load
- Should consider other factors, also:
  - traffic conditions
  - driver behavior
  - cold start effects
  - assumptions in the EPA tests and data use
- There is little or no difference between certification and production vehicles.
- Reasons not to change test:
  - the test has the precision needed to obtain valid repeatable laboratory results;
  - if the objective of the EPA estimate is to predict actual fuel economy, then tests must be developed to measure fuel economy under all possible circumstances;

  - it is better to test under known conditions [as in the current EPA test] and use results only for comparison;
  - the purpose of the MPG standards is to reduce gasoline consumption on a national basis; correlation between fleet fuel consumption (EPA test) and actual fuel economy is a constant: actual GPM = EPA GPM + 0.01.

TOSCO CORPORATION

° The EPA tests use high octane gasoline, while most in-use vehicles use lower octane fuels. This factor could contribute to the difference between actual fuel economy and EPA estimates.

C. Comments of Other Federal Agencies

The Departments of Energy and Transportation furnished information and guidance during the preparation of this report. These agencies were briefed on the study's findings at the time of completion of the first draft, and submitted comments on the draft. Their comments are reproduced in their entirety below, together with brief EPA responses to the comments.

The Federal Trade Commission was also briefed and given copies of the draft report; the FTC did not submit written comments.

Department of Energy
Washington, D.C. 20585

APR 9 1980

Mr. Michael Walsh
Deputy Assistant Administrator
Mobile Source Air Pollution Control
ANR-455
U.S. Environmental Protection Agency
Washington, D.C. 20460

Dear ~~Mr. Walsh~~ Mike:

I would like to thank you for the briefing your staff provided to the Department of Energy (as well as DOT and FTC) on your draft report Passenger Car Fuel Economy: EPA and Road - A Report to the Congress. The report is both comprehensive and of excellent technical quality. We are very impressed with the quality and thoroughness of the analysis Dill Murrell and Karl Hellman have done.

Both during the briefing and later we gave your staff technical comments on the work and its presentation. The only major point I want to restate here regards the treatment of 1979 model year data. By the nature of the "fleet" versus "consumer" weighting process used in the analysis, the EPA representation of 1979 MY shortfall is almost completely dependent on one manufacturer's (Ford) data. While we have no reason to doubt the validity of that data for Ford cars, it may not be representative of the general MY 1979 auto population. The GM MY 1979 "fleet" data is not only different in absolute shortfall, but it shows a different trend. We are not suggesting you change any conclusion you have reached but rather that any conclusion on the 1979 MY trend must be made with caution. This is all the more important since the auto manufacturers seem to now be taking the tack that "while there may have been a shortfall problem for 1974-1978, the 1979 (Ford) data shows that things are getting better."

While we hope this is true, DOE doesn't accept one year's data from one manufacturer as being definitive of future years' trends. Your report ought to be clear so as to avoid any unnecessary misuse.

One other point that does not appear to be addressed in the EPA report is the lack of data and analysis on inuse light truck fuel economy. While the report, almost by necessity, is focused on passenger cars, the light truck mpg shortfall problem may be even worse. The report should be specific with regard to this point so that it is not assumed that this data and analysis is equally applicable to trucks.

We are anxious for you to release the report in its final form. This will greatly improve understanding of the shortfall issue (by a number of interested parties). It is also necessary as part of the basis for the rulemaking on 1982 model year fuel economy labels, which we are anxious to begin. I am concerned that any further delay may foreclose action for the 1982 model year. DOE is prepared to offer comments, conduct analysis and present the results of our consumer survey work to support your rulemaking activity.

I would appreciate hearing from you as to what you schedule is for this action and what we can do to assist EPA. We are looking forward to working with you.

Sincerely,

Sydney Berwager

cc: Charles Gray - EPA
Dill Murrell - EPA
Marilyn Holmes - FTC
Barry McNutt - DOE

EPA Response

The predominance of Ford data in the 1979 data is pointed out in Section III.C, Representativeness of the Data Sample.

The report title, "Passenger Car Fuel Economy ..." describes what is addressed by the report; the Executive Summary indicates the need for in-use data on light trucks and vans.

U.S. DEPARTMENT OF TRANSPORTATION
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION
WASHINGTON, D.C. 20590

MAR 31 1980

IN REPLY REFER TO:

Mr. Michael P. Walsh
Deputy Assistant Administrator for
Mobile Source Air Pollution Control
Environmental Protection Agency
Washington, D.C. 20460

Dear Mr. Walsh:

This transmits comments of the National Highway Traffic Safety Administration (NHTSA), Department of Transportation (DOT), on the Environmental Protection Agency (EPA) draft report, "Passenger Car Fuel Economy: EPA and Road, A Report to the Congress." NHTSA review of this report has been coordinated with the Office of the Assistant Secretary for Policy and International Affairs, DOT.

Overall, the report presents an extremely broad treatment of the multitude of factors which can affect fuel economy, together with estimates of the effects of most of these individual influences. The incorporation of some 260 references must surely make the report the most comprehensive single document dealing with EPA versus on-road fuel economy, and indicates a very thorough and conscientious effort by the authors.

NHTSA's primary comment on the study concerns the relationship of the Executive Summary to the remainder of the report. In our view, findings and conclusions given in the Summary do not fully summarize the vast amount of technical information and effort that has gone into subsequent sections of the report. This shortcoming, we believe, also detracts from focusing on the main objectives of the "404 study" which were to: (1) Evaluate the reasons for deviation between EPA and consumer fuel economy and; (2) provide a basis for consumers to better evaluate the fuel efficiency they could expect to achieve as a function of individual driving characteristics, optional equipment, etc. The orientation here is to provide the consumer with better information on which to base a vehicle purchase decision and to predict the fuel economy he can expect to achieve in the real world. The study, as written, has achieved the first objective, but was not able to meet the second objective.

It is our recommendation that the Executive Summary be revised, and offer the following, more specific suggestions:

(1) Reconcile the information under Conclusion One, pages I-3 to I-8, concerning EPA-to-on-road shortfall with information given later in the report on the same topic. The Executive Summary states that a shortfall exists between EPA and on-road fuel economy, and that the shortfall is greater the higher the EPA rating. However, elsewhere in the report information is given to support a narrowing of this gap. For example on pages III-16, 17, it is indicated that since 1976, the shortfall for high mpg cars has decreased. Pages IV-108 and V-7-9 cite a tightening of test procedures and a projection of significantly increased penetration of diesel power and front-wheel drive technologies (features which show less dynamometer to road slip than their conventional technology counterparts), all of which should serve to decrease the shortfall gap. Further, on pages IV-17 and IV-172 vehicle usage factors are cited which could, in the past, have contributed to higher shortfalls for higher mpg cars, but which may well be changing as consumers begin to use small cars for other than primarily local travel. Some recent NHTSA research (Enclosure 1) supports this premise of changing vehicle usage.

(2) In view of the comments under (1), above, and degree of applicability to the study objective, reconsider the use of the charts and tables on longe-range, projected fuel consumption on pages I-3 through I-6. Such information concerning the implications on long term fuel conservation, has, we believe, only a secondary relationship relative to the primary one of consumer information, yet this information appears first in the discussion of Conclusion One.

(3) The final statement of page I-6 concerning fuel savings due to the standards should be qualified. Both the Congress and the DOT recognized at the outset that EPA fuel economy would not equal real-world fuel economy. Accordingly, NHTSA has employed a specific discount factor (11%) in all consumption projections in recognition of this historical shortfall.

(4) Some idea of the fuel economy slips due to individual factors, as covered at length in the text, should be included in the Executive Summary.

(5) Relative to the comments at the top of page 10 concerning future work, we suggest you also cite our "On-the-Road Fuel Economy Survey" as a source to fill the gap on light truck in-use data. The survey will also provide much needed nationally representative data on late model passenger car

> fuel economy. In this regard we believe more acknowledgement should be made in the Executive Summary of the present lack of nationally representative and statistically valid data for on road, consumer fuel economy data. Potential biases due to fleet data, lack of import representation, and odometer differences are given in the report in Section III. To these three reasons we would add a fourth: Existent data are comprised of various special purpose tests and brief surveys, as opposed to being based on a nationally valid, probability sample of consumer owned vehicles.

In addition to the Executive Summary, we suggest that the first paragraph under Section II-BACKGROUND be revised to reflect a third purpose for fuel economy data, namely, "to assist in the promulgation, enforcement, and evaluation of fuel economy standards." Along with this change, we propose the following paragraph to be inserted as paragraph number four (4) on page II-1: "Standards engineers and personnel concerned with standards enforcement and program evaluation need data to assist in: (1) the establishment of levels for future fuel economy standards; (2) determination of compliance with existing standards; and (3) to evaluate the real-world effects of those standards as to their energy conservation effects."

This concludes our comments on Sections I and II, the Executive Summary and Background. Enclosure 2 contains a few additional technical comments on Sections III-V.

We appreciate the opportunity to review this draft report. Should you require further information, please don't hesitate to contact me (426-1560).

Sincerely,

Barry Felrice
Associate Administrator
for Plans and Programs

2 Enclosures

EPA Response

The Executive Summary has been rewritten.

Conclusions regarding high-MPG cars' road shortfalls, and nationwide fuel consumption, have been modified to address only those model years for which there is actual road fuel economy data.

Conclusions on fuel savings associated with the standards now reflect a scenario in which assumed road MPG improvements parallel, but do not equal, EPA MPG.

In the Background section, we have clarified the point that the historical users of MPG figures were fuel demand forecasters and consumers, joined later by those responsible for management of fuel economy standards.

TSC F 1325.4 (5/78)

UNITED STATES GOVERNMENT

Memorandum

DEPARTMENT OF TRANSPORTATION
RESEARCH AND SPECIAL PROGRAMS ADMINISTRATION
TRANSPORTATION SYSTEMS CENTER

DATE: February 14, 1980

SUBJECT: Passenger Car Fleet Projection Parameters

Reply to attention of: DTS-321

FROM : John K. Pollard and K. H. Schaeffer

TO : Chief, Transportation Industry Analysis Branch, DTS-322

Contained in Tables 1-4 (attached) are estimates of passenger car sales and curb weight by size class for the years 1979-1990 as well as VMT and scrappage curves. Data sources, methodology and caveats associated with Tables 1-4 are described below.

1. Auto Sales By EPA Size Class

Retail sales of domestic and imported cars in calendar year 1979 were as shown below:

Class Size	Total	% by Class Size
Two Seaters	164,464	1.6%
Minicompact	672,387	6.4%
Subcompact	3,001,071	28.6%
Compact	1,431,680	13.6%
Mid-Size	3,343,279	31.8%
Large Size	1,897,352	18.1%
TOTAL	10,510,233	100.1%

Applying the 1979 percentage distribution by size class to the DRI "Trendlong 2004" passenger car sales forecast yields the results shown in Table 1. The DRI forecast was chosen because, in the opinion of TSC staff, it represents the best attempt to date to deal with the issue of light trucks and their substitution for passenger cars.

ENCLOSURE ONE

2. Curb Weights

Proprietary submissions from the four domestic manufacturers were used to compile the data shown in Table 2. Since no domestic mini-compacts are planned for production in the years 1981-84, weights for imports (e.g., Honda Civics) were used for those cells.

3. Survivability Data

Some analyses of survival data disaggregated by size class have shown an inverse relationship between size and longevity. (Domestic subcompacts have been an exception to this rule, but their early retirements reflect problems peculiar to the Vega and the Pinto. Imported subcompacts survive longer than the average of all domestic cars.) Relatively shorter lives for larger cars are consistent with the data on VMT by age which have shown that larger cars accumulate more miles per year. Survival data typically show small (compact) cars remaining in the fleet more than two years longer than full-sized cars of the same make, while being driven one to two thousand fewer miles per year. Several possible explanations for this traditional pattern of vehicle use have been offered, among them: (1) higher income families, who definitely travel more, prefer larger cars; and (2) multi-car households who have tended to use their larger cars for vacation and other long trips for reasons of comfort.

The sharp increase in the real price of gasoline in 1979 and the now widespread fears of continuing availability problems may have inverted the rationale for the traditional patterns of vehicle use. That is, individuals and families who want or need to drive a great many miles per year may now prefer smaller cars. Similarly, in the face of availability problems or gasoline rationing, the smaller car could become the vehicle of choice for vacation trips.

In light of the above, it is the judgment of TSC staff that currently available data on survival and VMT disaggregated by size class do not provide a good indication of future patterns of use. We would not go so far as to assume that the pattern will be completely inverted. Rather, our best guess is that the factors which favor higher utilization of small cars will roughly balance the factors which have traditionally favored the higher utilization of larger cars. Thus, we recommend the use of the same survival and VMT curves for all vehicle classes.

The survival data shown in Table 3 were calculated from R. L. Polk's registration data for July 1, 1977 and 1978. Since the Polk figures cover only 15 model years, survival factors for years 16 through 25 were estimated by extrapolating an assumed one year survival rate of 0.7, which produced an estimate of total car population greater than 15 years old consistent with Polk data.

4. Annual Mileage By Age

For the reasons described in Section 3, above, we recommend the use of the same schedule of annual miles travelled by age for all size classes.

The data shown in Table 4 are based upon the National Science Foundation's 1978 National Transportation Survey. The 1095 respondents to this survey completed questionnaires providing information on the make, model, age, and miles travelled during the past year on each of the 1766 vehicles in their households. From these data, a table showing mean mileage by age for passenger cars was constructed. Several curve fitting routines were tested on this table. Simple linear regressions yielded the highest r^2 value, .78. The equation is:

$$VMT_n = 12{,}012 - 427.39n$$

where VMT_n = miles travelled in year n

n = year of life

Since the survey data covered only eleven vintages, values for years 12 through 25 were extrapolated.

The smoothed data were then input to the TSC Auto Fleet Fuel Consumption Model ("FUEL3") along with the survival data from Section 3. The resulting estimate of total fleet VMT for 1978 was .940 trillion miles, some 19.7% less than the FHWA estimate of 1.17 trillion miles. This was to be expected since the NTS data cover private households only, whereas the total fleet contains a substantial fraction of business-use vehicles which are much more heavily utilized. To correct for this, the NTS derived mileages were multiplied by 1.246 and reinserted into FUEL3. The adjusted figures, shown in Table 4, result in an estimate of 1978 total fleet VMT of 1.17 trillion.

Attachments

cc:
DTS-321/R. Ricci

TABLE 1. AUTO SALES BY EPA SIZE CLASS

(annual sales in millions)

Year	Minicompact	Subcompact[1,2]	Compact[3]	Midsize[4]	Large[5]
1979	0.7	3.2	1.4	3.3	1.9
1980	0.6	2.8	1.3	3.0	1.7
1981	0.7	3.1	1.4	3.2	1.8
1982	0.7	3.3	1.5	3.4	1.9
1983	0.7	3.3	1.5	3.5	2.0
1984	0.7	3.3	1.5	3.5	2.0
1985	0.7	3.4	1.6	3.6	2.1
1986	0.8	3.6	1.6	3.8	2.1
1987	0.8	3.7	1.7	3.9	2.2
1988	0.8	3.6	1.6	3.8	2.2
1989	0.8	3.6	1.6	3.8	2.2
1990	0.8	3.7	1.7	3.9	2.2

Notes: [1] includes two-seaters

[2] includes subcompact wagons

[3] includes compact wagons

[4] includes midsize wagons

[5] includes large wagons

SOURCE: Data Resources, Inc., Trendlong forecast allocated to size classes according to 1979 actual percentages.

TABLE 2. ESTIMATED AVERAGE CURB WEIGHT (AS SOLD, INCLUDING OPTIONS) FOR DOMESTICALLY MANUFACTURED CARS

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Mini-Compact	2600	2600	1850[*]	1850[*]	1800[*]	1800[*]	1750	1750	1750	1750	1700	1700					
Subcompact	2700	2700	2500	2400	2400	2350	2150	2100	2100	2100	2100	2000					
Compact	3000	2800	2700	2700	2600	2600	2500	2400	2400	2350	2350	2350					
Mid-Size	3500	3350	3250	3250	2950	2950	2800	2800	2800	2750	2750	2700					
Large	4000	3900	3900	3800	3800	3450	3350	3300	3300	3250	3250	3200					

SOURCE: TSC Staff (based upon proprietary data submitted by domestic manufacturers extending to 1986 or 1987 and extrapolated to 1990).

[*] Values for mini-compacts marked with asterisk are for imports, since no domestic minis are scheduled for production in these years.

TABLE 3. SURVIVAL RATES FOR PASSENGER CARS

Year	Fraction of Original Production Still Registered (All Size Classes)
1	1.000
2	.992
3	.968
4	.951
5	.925
6	.884
7	.824
8	.750
9	.656
10	.550
11	.447
12	.356
13	.279
14	.219
15	.170
16	.119
17	.083
18	.058
19	.041
20	.029
21	.020
22	.014
23	.010
24	.007
25	.004

SOURCE: R. L. Polk & Co., registration data for July 1, 1977 and 1978; years 16 through 25 extrapolated at an assumed one year survival rate of 0.7.

TABLE 4. VMT BY AGE

Year	Miles Travelled per Vehicle, All Size Classes (Thousands)
1	14.436
2	13.903
3	13.371
4	12.838
5	12.306
6	11.773
7	11.240
8	10.708
9	10.176
10	9.643
11	9.110
12	8.577
13	8.045
14	7.513
15	6.980
16	6.447
17	5.927
18	5.382
19	4.850
20	4.317

EPA Response

Enclosure One (1) of the DOT comments was prepared prior to receipt by DOT of EPA's first draft, and is not a direct comment on the report. The information is useful, and is appreciated. EPA would suggest that DOT reconsider the assumption, implied by Table 1, that the mix of car size classes will remain constant through 1990.

NHTSA COMMENTS ON SECTIONS III-V
DRAFT REPORT, "PASSENGER CAR FUEL ECONOMY: EPA AND ROAD"
A REPORT TO THE CONGRESS
U.S. ENVIRONMENTAL PROTECTION AGENCY

January 1980

- o Page IV-15. The analogies here are misleading even though the author admits to "a bit of far-fetchedness." A chemical reaction and the use of db which is on a logarithmic scale do not illustrate the point that all slips are not additive. A simple analogy utilizing the factors in point (vehicle and environmental factors) would be much more useful.

- o Page IV-16. It would seem that the more frequent tune-up interval attributed to smaller engines would be related to owner perceived reduction in performance rather than less improvement per tune-up. Obviously, a malfunction which affects one cylinder will have a proportionately greater effect on a 4-cyl. engine than an 8-cyl. engine.

- o Pages IV-76-78. The effect of grades of fuel economy is calculated by using steady state fuel consumption values. It should be pointed out that steady state fuel consumptions will likely underestimate the effect of grades since transient throttle excursions will cause accelerator pump injections, short periods of power enrichment and other nonsteady state phenomena which will likely degrade fuel economy.

- o Pages IV-112 & 113. The discussion on the pitfalls inherent in making value judgments such as best or worse based on fuel economy misses the point. The only message contained in the table at the bottom of IV-112 is that people who drive more miles may consume more fuel even though they achieve greater mpg. I believe we understand the intention but the message that is coming forth from the illustration is not appropriate.

- o Page IV-130. The DOT study used electronic flow meters to indicate fuel efficiency and the conclusion regarding manifold vacuum gauges is therefore inappropriate.

- o Page IV-138. The conclusion is drawn that fuel savings from friction reducing oils may be lost if drivers use the friction reduction for added performance. The notion that drivers would begin "hot-rodding" their vehicles after gaining one or two horsepower is stretching the imagination a bit too far. The most important slip is the one ignored, a positive slip due to the fact that the improvement on the dyno is far less than that achieved in the real world.

- o Page IV-146. The section on lubricants skirts the issue of current practices by stating that EPA has not knowingly given approval for use of "slippery lubes." How do we reconcile the Honda experience with low viscosity lubes and the fact that the current Ford certification oil (which is not the oil used as factory fill) exhibits fuel efficiency characteristics equivalent to most publicized slippery lubes?

ENCLOSURE TWO

- Page IV-154. The discussion of errors created by the energy and velocity discrepancies is straight forward and the thought that coupling the rollers will eliminate those errors is plausible. However, the conclusion that this difference is a measure of the road shortfall is rather vague. Given that the twin-roll dyno results in unnatural distortion and loading of tires in the first place, it is difficult to reconcile that coupling of the two rolls will immediately make the tire losses representative of the real world. It would seem that the different response of radials vs. bias, front-wheel drive vs. rear-wheel drive and all the other anomalies would have to be considered prior to drawing any conclusions regarding the representativeness of the coupled rollers.

- Page VI-160. The statement is made that power steering operational data is not available to evaluate whether a shortfall exists due to lack of turning of the front wheels during tests. We suggest that any one of the following will provide a good indication of this loading:

  1. Program Summary Report Study on Reduction of Accessory Horsepower Requirements, Air Research Manufacturing Company, June 15, 1977.
  2. Automotive Accessory Drive System Study, 74-310772, Air Research.
  3. C.W. Coon et al, Technological Improvements to Automobile Fuel Consumption, Vol. IIA, DOT-TSC-OST-74-39. December 1974, (Southwest Research Institute).
  4. C. Marks, "Which Way to Achieve Better Fuel Economy," General Motors Engineering Staff, Detroit, Michigan, December 3, 1973.

- Pages V-6, 7. An estimate of 14% diesel penetration in 1985 is made using the "Pearl Equation." It is suggestd that the DOT submission with regard to diesel penetration (9% in 1985) to the Three Agency Diesel Task Force is a much more reliable estimate of this value. The claim is made that the G.M. estimate supports this figure. The G.M. estimate is of their own penetration; given that Ford and Chrysler as well as a number of the importers plan little or no diesels it is difficult to reconcile 15% as a number for the total car fleet.

- Page V-8. G.M. is quoted as projecting 50% front-wheel drive by the mid-1980's (June 8, 1979, Ward's Engine Update). This estimate has long been superseded by announcements which place this projection at 90-95% (e.g., Motor, Oct. 1979). Further, Chrysler has said 100% FWD by 85 and Ford is now projecting 40-50 % by 85 and 100 % by 86-87.

  It is therefore concluded that the estimates for FWD in the two scenarios are too low. At least a third scenario should be added which places FWD penetration at 90-100%.

- In view of the emphasis on "running changes" in recent Congressional hearings and in the media, we suggest this factor be added to the report, along with appropriate comments.

- To the above we would like to add one general comment. Whereas many sources of data and test results are cited in the report, there seems to be a rather universal lack of interpretive comments concerning the sources as to their strong, weak points etc. For example, in the conflicting data on tune-ups (pages IV-48, by Claffey), is it not possible that some of the difference in mpg could be due to inadequately performed tune-up work? Also concerning the EPA 75-76 RM data, it may be that insufficient data are available in the small engine category (i.e., say 100-150 CID) to draw definite conclusions. In the interpretive comments, the -0.7% mpg for <225 CID engines may not be a true indication, but may be due to random variation. Were all tests done by the same laboratory with the same technicians, test/tune-up equipment, etc.? All of these are potential sources of variation in fuel economy results.

EPA Response

Many of the comments in Enclosure Two (2) are editorial; some have led to corrections, some have not. All are acknowledged and are appreciated.

Surveillance over the certification use of "slippery lubricants" is hampered by the non-existence, at this time, of a precise system for classifying oils as to vehicle fuel efficiency potential. In the "Honda experience", EPA questioned the representativeness of the engine lube oil used in some Honda test cars. Honda was required to rerun those cars using oil that was considered representative. Thus, EPA took action which was equivalent to disapproving use of an unrepresentative oil. In the case of Ford, certification vehicles use an unexotic oil, [Brand Name] 10W-30, which is commercially available and is not excessively costly. The DOT comment suggests that there is something unusual about use in certification of oils which are not used for factory fill. This is not at all unusual: factory-fill oils are frequently "break-in oils", while certification oils resemble, or at least should resemble, post-break-in refill oils.

Data on the fuel economy effects of power steering under parametric test conditions is not in short supply. What is needed is data on the frequency and degree of turning experienced by vehicles in actual use.

It is acknowledged that EPA's crystal balls may be subject to clouding, with regard to the prediction of future market shares of Diesels and front wheel drives. The report now specifies, as it should have in draft, that Section V is an illustration. It should be noted, though, that "forecasted" road MPG, at 27.5 EPA MPG, varies by less than one MPG from the most optimistic Diesel and front drive scenario to a scenario in which there are virtually no Diesels or front wheel drives at all.

APPENDICES

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APPENDIX A

Method for Averaging Fuel Economy Data

Suppose a motorist takes the following trips:

200 miles, using 15.0 gallons;
100 miles, using 9.4 gallons;
140 miles, using 11.8 gallons.

The fuel economies of these trips are:

$$\frac{200 \text{ miles}}{15.0 \text{ gal.}} = 13.33 \text{ MPG};$$

$$\frac{100 \text{ miles}}{9.4 \text{ gal.}} = 10.64 \text{ MPG};$$

$$\frac{140 \text{ miles}}{11.8 \text{ gal.}} = 11.86 \text{ MPG}.$$

By merely averaging the trip MPG's, the motorist would calculate:

$$(13.33 + 10.64 + 11.86) \div 3 = 11.94 \text{ MPG}$$

But this is incorrect. The motorist traveled 440 miles and used 36.2 gallons, so the overall fuel economy was:

$$440 \div 36.2 = 12.15 \text{ MPG}$$

To calculate fuel economy correctly for multiple trips, the following equation must be used:

$$\frac{Miles}{Gallon} = \frac{Total\ Miles\ Traveled}{Total\ Gallons\ Used} \qquad \text{(A-1)}$$

If the individual trip lengths and fuel economy values are known, but the gallons used are not known, the proper equation is:

$$MPG = \frac{Miles_1 + Miles_2 + \ldots + Miles_N}{\dfrac{Miles_1}{MPG_1} + \dfrac{Miles_2}{MPG_2} + \ldots + \dfrac{Miles_N}{MPG_N}} \qquad \text{(A-2)}$$

where: miles_x = length of trip "x";
MPG_x = gas mileage for trip "x"; and
N = number of trips.

If all of the trips are of the same length (such as in a standardized test), equation A-2 is equivalent to:

$$MPG = \frac{Miles_t \times N}{Miles_t \left(\frac{1}{MPG_1} + \frac{1}{MPG_2} + \ldots + \frac{1}{MPG_N}\right)} \qquad \text{(A-3)}$$

where: $miles_t$ = the standard test length, and

N = the number of tests.

Equation A-3 simplifies to:

$$MPG = N \div \sum\left(\frac{1}{MPG_N}\right)$$

which is the "harmonic average" of the test MPG's.

If only trip MPG values (but not trip lengths) are known, no averaging technique assures accurate computation of cumulative MPG; however, the harmonic average always gives a more conservative (lower) estimate than the arithmetic average[244].

---

[244] McNutt et al, "A Comparison of Fuel Economy Results from EPA Tests and Actual In-Use Experience, 1974-1977 Model Year Cars (Appendix A)", SAE paper 780037, February 1978.

APPENDIX B

Examples of Averaging and Regression Analysis Methods

A large (>1500 car) data base on in-use fuel economy has been extensively analyzed by EPA. The following analysis results illustrate how different conclusions can be drawn from the same data, depending on the method of analysis. No one method or conclusion is "more correct" than any of the others. Note that even the average fuel economy is subject to some debate.

A. Average Values

	Mean Value	Standard Deviation	Implied Avg. MPG	Implied Road MPG Shortfall
Road MPG	13.76	3.44	13.76[a]	12.9%
EPA (55/45) MPG	15.79	3.43	15.79[a]	
Road GPM	0.07678	0.0174	13.02[b]	14.5%
EPA GPM	0.06572	0.0113	15.22[b]	
ln(Road MPG)	2.593	0.234	13.37	13.6%
ln(EPA MPG)	2.739	0.191	15.48	
ln(Road GPM)	-2.593	0.234	13.37	13.6%
ln(EPA GPM)	-2.739	0.191	15.48	
Road MPG - EPA MPG	-2.030	2.28	---	12.9%[c]
Road GPM - EPA GPM	0.01106	0.0127	---	14.4%[d]
Road MPG/EPA MPG	0.875	0.134	---	12.5%[c]
Road GPM/EPA GPM	1.172	0.194	---	14.7%[d]

---

[a] Arithmetic Average

[b] Harmonic Average

[c] Using Arithmetic Average EPA MPG

[d] Using Harmonic Average EPA MPG

B. Regression Equations (R = Road MPG, E = EPA MPG)

	Correlation Coefficient	Standard Error	Implied Road MPG Shortfall:	
			E = 15 MPG	E = 25 MPG
$R = 1.401 + .7827[E]$[e]	0.780	2.15	12.4%	16.1%
$R = -24.41 + 13.93[\ln(E)]$	0.775	2.17	11.2%	18.3%
$R = 28.94 - 231.1[1/E]$	0.758	2.24	9.8%	21.2%
$\ln(R) = .1109 + .9062[\ln(E)]$	0.742	0.157	13.3%	17.4%
$\ln(R) = 1.800 + .05027[E]$	0.737	0.158	14.3%	17.4%
$\ln(R) = 3.593 - 15.22[1/(E)]$	0.734	0.159	12.2%	20.9%
$1/R = .007372 + 1.056[1/E]$[f]	**0.683**	0.0127	**14.3%**	**19.4%**
$1/R = .2471 - .06216[\ln(E)]$	0.683	0.0127	15.4%	14.9%
$1/R = .1306 - .03496[E]$	0.670	0.0129	16.2%	12.0%
$E - R = -1.401 + .2173[E]$	0.327	2.15	12.4%	16.1%
$E - R = -8.472 + 3.834[\ln(E)]$	0.322	2.16	12.7%	15.5%
$E - R = 6.201 - 63.47[1/E]$	0.314	2.16	13.1%	14.6%
$R/E = .7827 + 1.401[1/E]$	0.118	0.133	12.4%	16.1%
$R/E = 1.095 - .08055[\ln(E)]$	0.115	0.134	12.3%	16.4%
$R/E = .9437 - .004375[E]$	0.112	0.134	12.2%	16.6%
$1/R - 1/E = .01451 - .000218[E]$	0.059	0.0127	14.4%	18.5%
$1/R - 1/E = .02118 - .003692[\ln(E)]$	0.055	0.0127	14.4%	18.9%
$1/R - 1/E = .007372 + .05619[1/E]$	0.050	0.0127	14.3%	19.4%

---

[e] "Fuel economy" regression

[f] "Fuel consumption" regression

APPENDIX C

Energy Balance for a Synthetic Motor Oil[245]

	BTU's Per 6,000-Mile Drain Period
AUTOMOBILE FUEL ECONOMY EFFECT	
Conventional SAE 10W-40 @ 15 mpg	
6,000 miles/15 mpg = 400 gallons	
400 gallons X 116,000 BTU/gallon	46,400,000
Synthetic @ 15.6 mpg (4% Improvement)	
6,000 miles/15.6 mpg = 385 gallons	
385 gallons X 116,000 BTU/gallon	44,615,000
Net Automobile BTU Savings	1,785,000
PROCESSING ENERGY EFFECT	
Conventional SAE 10W-40 (5 quarts charge plus 3 quarts makeup)	
Processing energy including atmospheric and vacuum distillation, solvent extraction and dewaxing, and additive preparation = 19,000 BTU/quart	
19,000 BTU/quart x 8 quarts	152,000
Synthetic (5 quarts charge plus 2 quarts makeup)	
Processing energy including preparation of SHF stock, ester, and additives = 37,000 BTU/quart	
37,000 BTU/quart x 7 quarts	259,000
Net Processing Energy Increase	107,000
ENERGY SAVINGS	
Automobile savings	1,785,000
Processing energy increase	-107,000
Net savings	1,678,000

---

[245] Marshall, "Survey of Lubricant Influence on Light-Duty Vehicle Fuel Economy", Coordinating Research Council Report 502, December 1978.

APPENDIX D

Relation Between Home-to-Work Trip Speed and Trip Speed for Non-Work Travel

A traffic survey[246] on the Los Angeles road route corresponding to the EPA urban driving schedule shows the following average traffic speeds as a function of time of day:

	Average Speed
7-9 a.m. and 3-5 p.m. (4 hours)	17.4 mph
9-11 a.m. and 1-3 p.m. (4 hours)	21.0 mph

Relative traffic densities can be estimated from time-of-day distributions of vehicle travel[247]:

	Fraction of Daily VMT	Relative Traffic Density
7-9 a.m. and 3-5 p.m. (4 hours)	31.30%	1.656
9-11 a.m. and 1-3 p.m. (4 hours)	18.90%	1.000
Other daylight hours (7 hours)	37.00%	1.119
9 p.m. - 6 a.m. (9 hours)	12.80%	0.301

An equation (the Greenshields formula[248]) relating average speed to traffic density is:

$$V = V_f \left(1 - d/d_j\right)$$

where: V = average speed;
V_f = free-flow speed;
d = traffic density;
d_j = jam density.

---

[246] Scott Research Laboratories, "Vehicle Operations Survey", CRC/EPA Project No. CAPE-10-68(1-70), December 1971

[247] Svercl and Asin, "Nationwide Personal Transportation Study, Home-to-Work Trips and Travel, Report No. 8", DOT/FHwA, August 1973.

[248] Voorhies, et al, "Vehicle Operation, Fuel Consumption and Emissions as Related to Highway Design and Operation", Interim Report for DOT/FHwA, October 1977.

This equation is equivalent to:

$V = a + b(RTD)$ where: "a" and "b" are constants, and
RTD = relative traffic density.

Using the preceding data in this equation (we are here assuming that nationwide relative traffic densities by time of day are applicable to the Los Angeles route),

$$17.4 = a + b(1.656) \quad \text{and} \quad 21.0 = a + b(1.000)$$

Which yields a = 26.49 and b = -5.49. Applying this to the two other time blocks, we have:

	Average Speed
7-9 a.m. and 3-5 p.m.	17.4
9-11 and 1-3 p.m.	21.0
Other daylight hours	20.4
9 p.m. - 6 a.m.	24.8

It has been shown[249] that average night driving speeds are lower than daytime speeds; accounting for this, the traffic density-derived 24.8 mph night average speed becomes 23.8 mph.

The NPTS report gives the following distributions of vehicle-miles traveled by trip purpose, and time of day:

	Work Travel	Non-Work Travel
7-9 a.m. and 3-5 p.m.	44.64%	24.55%
9-11 a.m. and 1-3 p.m.	10.42%	23.19%
Other daylight hours	34.22%	38.40%
9 p.m. - 6 a.m.	10.72%	13.86%
	100.00%	100.00%

---

[249] Claffey, "Passenger Car Fuel Conservation", DOT Report FHwA-PL-77009, January 1977. (Urban test route, 75 drivers).

Combining these distributions with the average traffic speed values for the four time blocks (44.64% of work travel is conducted in traffic flowing at 17.4 mph, etc.), the following VMT-weighted average speeds are obtained:

Work Travel:
$$V_w = \frac{100.0}{\frac{44.64}{17.4} + \frac{10.42}{21.0} + \frac{34.22}{20.4} + \frac{10.72}{23.8}} = \underline{19.27}\ \text{mph}$$

Non-Work Travel:
$$V_{nw} = \frac{100.0}{\frac{24.55}{17.4} + \frac{23.19}{21.0} + \frac{38.40}{20.4} + \frac{13.86}{23.8}} = \underline{20.08}\ \text{mph}$$

All Travel:
$$V_{all} = \frac{100.0}{\frac{31.30}{17.4} + \frac{18.90}{21.0} + \frac{37.00}{20.4} + \frac{12.80}{23.8}} = \underline{19.80}\ \text{mph}$$

Since the absolute values for these average speeds are unique to this particular Los Angeles route, the relative values are more generally applicable:

$$\frac{\text{mph}_{non\text{-}work}}{\text{mph}_{work}} = \frac{20.08}{19.27} = 1.042$$

$$\frac{\text{mph}_{all\ travel}}{\text{mph}_{work}} = \frac{19.80}{19.27} = 1.028$$

APPENDIX E

Computations of Travel Characteristics and Effects

A. Factors Related to Annual VMT

- The Nationwide Personal Transportation Study[250] shows that, in 1969, personal passenger vehicles of all ages had annual VMT (vehicle miles traveled) averages of 11,105 miles for urban households and 15,387 for rural households, based on a questionnaire survey of approximately 6000 households. A 1975 survey by General Motors[251] of approximately 2000 owners of new GM cars showed annual VMT averages of 13,968 for urban areas and 17,015 for rural areas. These VMT rates are more applicable to a late-model, new-car analysis than the NPTS rates.

- The GM survey also reveals differential mileage accumulation rates as a function of car size (as do other studies[252-254]). The GM data are separable into rural and urban strata, and show the following differential VMT rates as a function of vehicle weight:

  Urban: 170.5 Δmiles/year per 100 lb. Δweight

  Rural: 142.4 Δmiles/year per 100 lb. Δweight

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[250] Goley, et al,"Nationwide Personal Transportation Study, Household Travel in the United States, Report No. 7", DOT/FHwA, December 1972.

[251] Unpublished.

[252] Scardino, et al, in "Impact of the FEA/EPA Fuel Economy Information Program", FEA Report No. ISBN: 0-89011-487-0, June 1976, showed that intermediate and larger cars accumulated 641 miles per year (average) more than compact and smaller cars;

[253] Canada Department of the Environment, in "Canadian Automobile Driver Survey", Report EPS 3-AP-73-10, October 1973, finds a VMT average difference of 570 miles per year for the same two broad divisions of car sizes;

[254] Data (unpublished) furnished to EPA by Mobil Oil Co. shows average differences in VMT rates of 1800 miles per year for [larger] cars with 300 CID engines compared to [smaller] cars with 100 CID engines.

- For 1976, the median year of the five model years considered in this report, small cars' average weight is 2650 lb. and large cars' average weight is 4320 lb[255].

- Urban and rural areas differ as to proportioning of registrations between small and large cars [256], small cars constituting 35.3% of all urban registrations but only 28.6% of rural registrations.

- The NPTS[257] gives trip and VMT fractions by season and place of residence as follows:

		Spring	Summer	Fall	Winter	Total
Trips:	Urban (incorporated)	26.2%	25.0%	25.6%	23.2%	100%
	Rural (unincorporated)	28.3%	24.4%	23.8%	23.5%	100%
VMT:	Urban	24.7%	28.8%	25.2%	21.3%	100%
	Rural	26.9%	27.3%	23.0%	22.8%	100%

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[255] from EPA data, unpublished.

[256] Shonka, "Transportation Energy Conservation Data Book, Edition 3", Oak Ridge National Laboratory Report ORNL - 5493, February 1979.

[257] Strate, "N.P.T.S., Seasonal Variations of Automobile Trips and Travel, Report No. 3", DOT/FHwA, December 1972.

B. Trip Length and Frequency

As discussed above, increases in total VMT from the NPTS values can stem from increases in trip length, trip frequency, or both.

Growth in average trip length has been reported by Tobin and Horowitz[258] for various trip purpose categories as follows:

	Annual Growth Rate
Work-Related trips	0.9% - 1.5%
Shopping	1.3% - 2.8%
Social/Recreational	0.5% - 0.7%
Non-Home based	0.7% - 2.5%

The VMT growth (relative to NPTS averages) discussed in the preceding section is greater than even the maximum trip length growth rates above would explain; evidently some of the VMT difference is due to vehicle "newness" in terms of age. Noting that the newest cars, and highest VMT values, in the NPTS data correspond to higher income brackets[259], we can infer, using high income travel characteristics in NPTS Report 7 (Table A-6), that high new-car VMT results much more from increases in trip frequency than trip length. Applying nominal trip length growth rates from Tobin and Horowitz, and accounting for the balance of the VMT difference using "new-car" trip frequency and trip length changes scaled from that NPTS table, we estimate the following adjusted trip characteristics for new vehicles, circa model year 1976.

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[258] Tobin and Horowitz, "The Influence of Urban Trip Characteristics on Vehicle Warmup -- Implication for Urban Automotive Fuel Consumption", SAE Paper 790656, June 1979.

[259] Strate, "N.P.T.S., Annual Miles of Automobile Travel, Report No. 2", DOT/FHwA, April 1972.

NPTS Trip Characteristics Adjusted for New-Car VMT and Seven Years' Growth in Trip Length (Model Year 1976 represented)

	Urban Households:			Rural Households:		
	Trip Length	Trips Year	Miles Year	Trip Length	Trips Year	Miles Year
1. NPTS Data						
Work-Related	9.54	483	4609	11.48	561	6438
Family Business	4.92	406	1999	6.73	493	3316
Educ./Civic/Rel.	4.05	118	478	5.85	157	918
Social/Recr.	13.02	301	3920	13.26	336	4455
Other	7.69	13	100	12.38	21	260
All Purposes	8.41	1321	11105	9.81	1568	15387
2. Adjusted Data						
Work-Related	10.99	549	6034	12.58	576	7246
Family Business	5.77	461	2660	7.82	501	3918
Educ./Civic/Rel.	4.35	142	618	6.14	161	989
Social/Recr.	13.44	348	4677	14.01	341	4777
Other	8.20	16	131	13.83	21	290
All Purposes	9.31	1516	14120	10.63	1600	17220

The next three matrices present the corresponding trip characteristics, broken out by car size and season of the year, derived from all of the above data.

Average Vehicle Miles Traveled, New Cars, 1976

	Urban Households:		Rural Households:	
	Small Cars	Large Cars	Small Cars	Large Cars
Spring	3025	3740	4167	4818
Summer	3526	4362	4230	4890
Fall	3086	3816	3563	4120
Winter	2608	3225	3532	4084
Total	12,245	15,143	15,492	17,912

Average Number of Trips, New Cars, 1976

	Urban Households	Rural Households
Spring	397	453
Summer	379	390
Fall	388	381
Winter	352	376
Total	1516	1600

Average Trip Length, New Cars, 1976

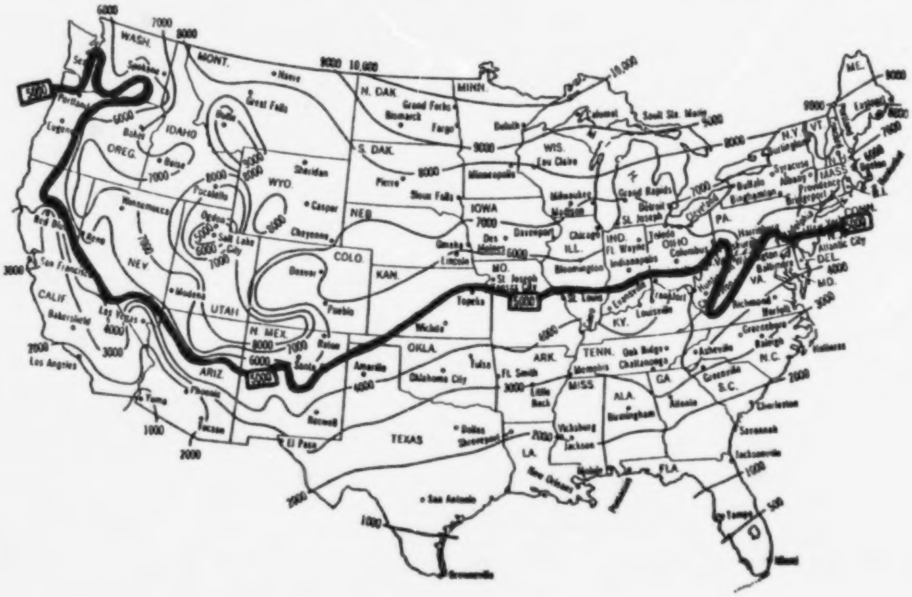
	Urban Households:		Rural Households:	
	Small Cars	Large Cars	Small Cars	Large Cars
Spring	7.62	9.42	9.20	10.64
Summer	9.30	11.51	10.85	12.54
Fall	7.95	9.84	9.35	10.81
Winter	7.41	9.16	9.39	10.86
Overall	8.08	9.99	9.68	11.20

C. Average Vehicle Speed and Regional VMT

Section IV.C.2.c(1) concluded that the "maximum speed" interpretation of NPTS trip speed data gives the best agreement with recent GM and EPA trip survey data. One additional factor: the Canadian survey cited previously indicates that average speeds for commuting trips in Canada are some 7% slower in Winter than in Summer. The GM and EPA trip surveys were conducted in the months of March-June and March-April, respectively, and would not fully reflect this influence.

We account for this, as a first-level approximation, by dividing the U.S. into two zones, separated more or less by the 5000 degree-day/year contour on Figure APX-1 [260], and by Federal Region boundaries on Figure APX-2 [261].

FIGURE APX-1. Normal Number of Degree Days Per Year.


5000
WASH.
MONT.
IDAHO
OREG.
WYO.
N. DAK.
S. DAK.
MINN.
WIS.
IOWA
NEB.
COLO.
KAN.
MO.
ILL.
IND.
OHIO
PA.
N.Y.
VT.
ME.
MASS.
CONN.
DEL.
MD.
VA.
KY.
TENN.
N.C.
S.C.
GA.
ALA.
MISS.
ARK.
LA.
FLA.
OKLA.
TEXAS
N. MEX.
ARIZ.
UTAH
NEV.
CALIF.

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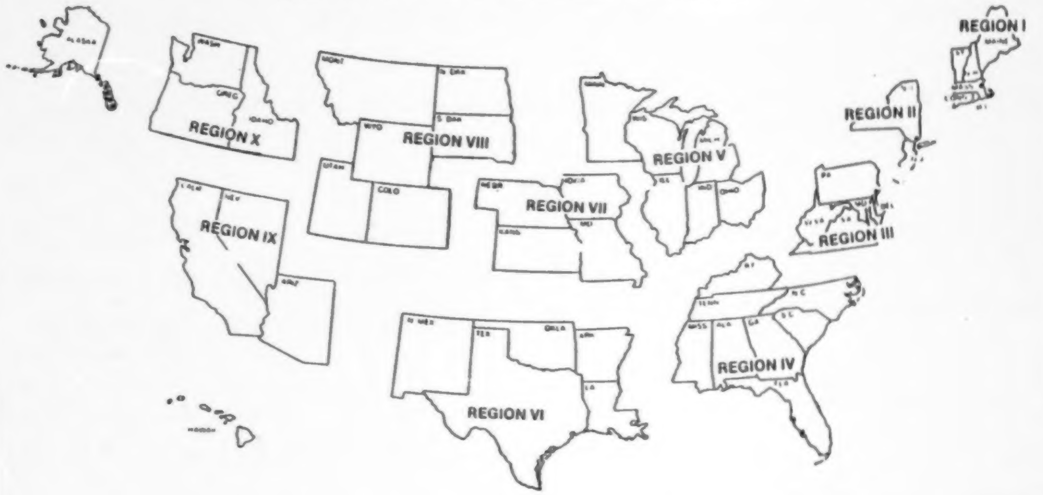
[260] American Society of Heating, Refrigerating, and Air Conditioning Engineers, ASHRAE Handbook, 1978.

[261] Greene, et al, "Regional Transportation Energy Conservation Data Book", Oak Ridge National Laboratory Report ORNL - 5435, September 1978.

FIGURE APX-2. United States Federal Regions


REGION I
REGION II
REGION III
REGION IV
REGION V
REGION VI
REGION VII
REGION VIII
REGION IX
REGION X

Principal characteristics of these two zones are as follows:

	North Zone	South Zone
Regions/(States) Included	I,II,(PA,WV),V VII,VIII,(NV),X	III(except PA & WV), IV,VI,IX(except NV)
Zone fraction of U.S. VMT	53.5%	46.5%
Urban VMT fraction in Zone	58.7%	51.5%

Trip average speed values determined from the trip length data and from zonal considerations are given in the next matrix.

Average Trip Speeds, New Cars, 1976

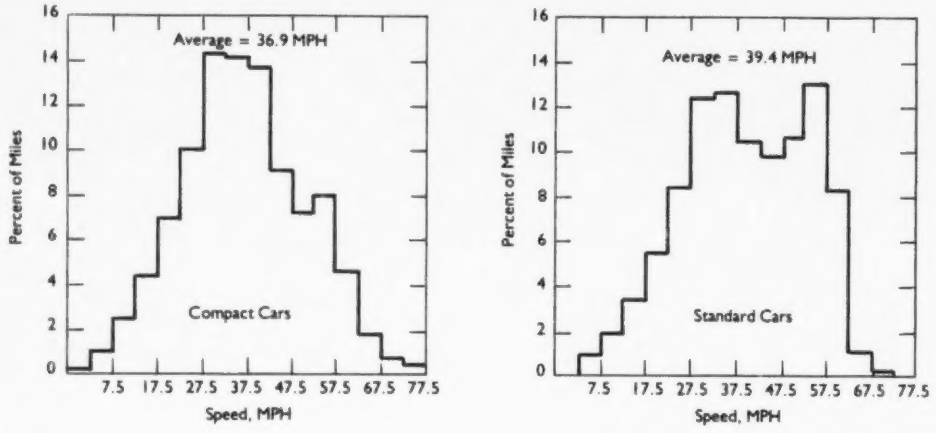
		Urban Households:		Rural Households:	
		Small Cars	Large Cars	Small Cars	Large Cars
Spring,	North	30.7	31.5	31.4	32.8
	South	31.3	32.2	32.0	33.5
Summer,	North	32.1	34.8	33.8	36.1
	South	32.1	34.8	33.8	36.1
Fall,	North	31.2	32.0	31.8	33.4
	South	31.5	32.3	32.1	33.8
Winter,	North	29.9	30.8	30.9	31.5
	South	31.1	32.0	32.1	32.8
All		31.2	32.6	32.3	33.8

The corresponding VMT distributions are shown in the next matrix:

		Urban Households:		Rural Households:	
		Small Cars	Large Cars	Small Cars	Large Cars
Spring,	North	.0274	.0501	.0170	.0424
	South	.0209	.0383	.0174	.0433
Summer,	North	.0319	.0585	.0173	.0431
	South	.0244	.0446	.0176	.0440
Fall,	North	.0279	.0512	.0145	.0363
	South	.0213	.0391	.0149	.0371
Winter,	North	.0236	.0432	.0144	.0360
	South	.0180	.0330	.0147	.0367
All		.1954	.3580	.1278	.3188

The above analysis yields overall average speeds of 31.7 mph for small cars, and 33.2 mph for large cars. These values are--if anything--conservative in both absolute level and car size differential, compared to the findings of an extensive GM traffic survey[262], as indicated in the figure below.

FIGURE APX-3. Percent of Miles Spent in Speed Bands



D. Relative Fuel Economy

Fuel economy performance as a function of trip length was modeled using the preceding trip length:average speed relations and data given in the text for acceleration intensity penalties (which vary with average speed), and warmup fuel consumption (which varies with average speed and trip time).

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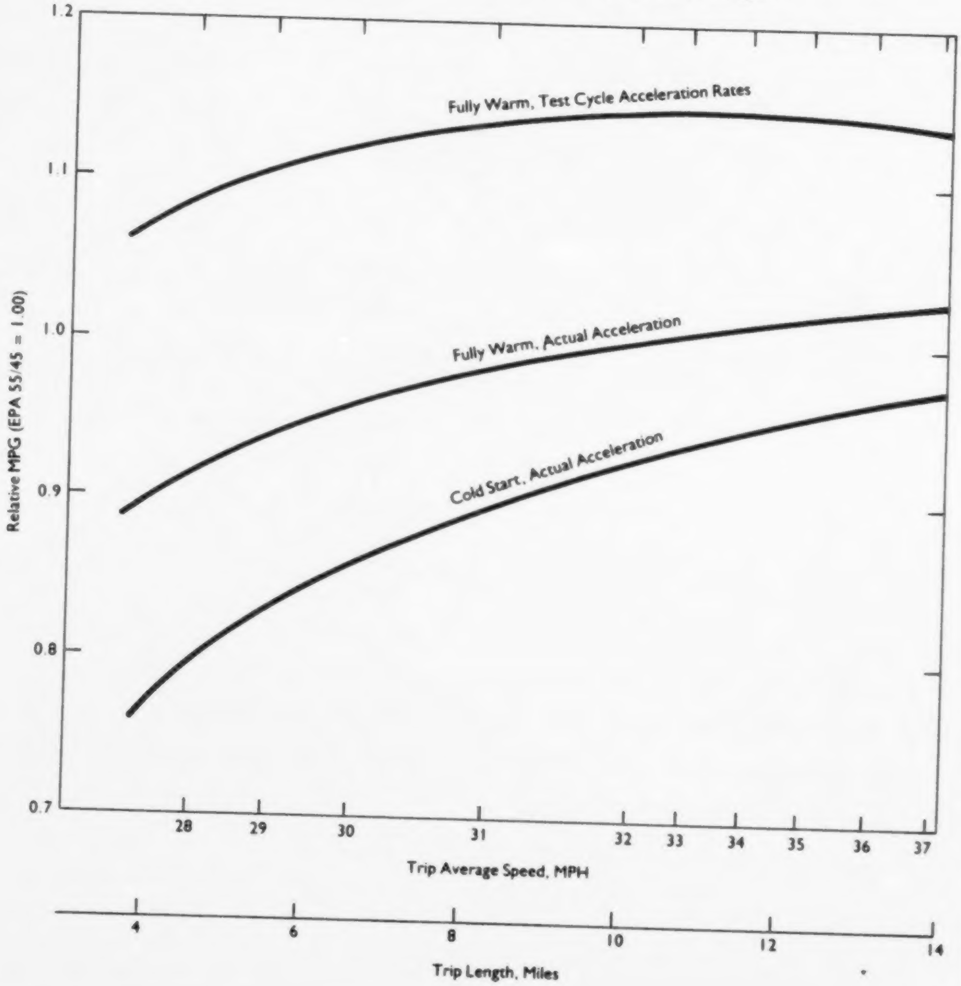
[262] Johnson, et al, "Measurement of Motor Vehicle Operation Pertinent to Fuel Economy", SAE Paper 750003, February 1975.

The resultant data were normalized to an EPA 55/45 cycle fuel economy reference value developed from the same model. The next figure shows normalized trip MPG versus trip length for the base case (with no penalty for excessive acceleration), and for fully-warmed up and cold start trips with acceleration penalties reflecting real-world observations.

FIGURE APX-4. Relative Fuel Economy vs. Trip Length



This model is the basis for the following matrix of normalized MPG values.

Relative Fuel Economy (EPA 55/45 = 1.000)

			Urban Households:		Rural Households	
			Small Cars	Large Cars	Small Cars	Large Cars
Spring,	North,	Cold Start	.883	.915	.912	.934
		Hot	.977	.995	.993	1.006
	South,	Cold	.892	.924	.921	.943
		Hot	.987	1.005	1.003	1.016
Summer,	North,	Cold	.922	.955	.946	.968
		Hot	1.003	1.022	1.017	1.028
	South,	Cold	.922	.955	.946	.968
		Hot	1.003	1.022	1.017	1.028
Fall,	North,	Cold	.894	.925	.918	.940
		Hot	.985	1.005	.999	1.012
	South,	Cold	.899	.929	.922	.944
		Hot	.990	1.010	1.004	1.017
Winter,	North,	Cold	.871	.901	.905	.928
		Hot	.963	.983	.985	.998
	South,	Cold	.889	.919	.923	.946
		Hot	.983	1.003	1.005	1.018

The proportioning of vehicle travel between "cold start" and hot start trips depends on the pre-start "soak" time which defines a cold start; this is a function of travel patterns (trip frequency and time between trips), and ambient temperature.

A driving pattern survey[263] which gathered extensive data on trip frequencies and distributions throughout typical weekdays and weekend days in six urban areas yields the following definition of cold start fraction as a function of minimum soak time:

Fraction of Engine Starts Which Are Cold Starts

Minimum Soak Time for Cold Start	North	South
8 hours	28.0%	23.9%
6 hours	30.0%	26.7%
4 hours	35.6%	31.6%
2 hours	44.1%	43.1%

To clarify: if 8 hours of soak are required for an engine start to be a "cold start", only those trips which begin after soaks of at least 8 hours are cold starts; if soaks of 4 hours are sufficient to make a start a "cold start", those additional trips preceded by soaks of 4 to 8 hours qualify as cold starts, and the cold start fraction is higher.

Engine cooldown data from a soak time effects study[264] can be used to estimate what soak time defines a cold start. The selection of a specific engine temperature to define a start as "cold" is not exact; in this study, 130°F was judged to be appropriate based on examination of relative fuel economy vs. engine temperatures, after various soak intervals. (A difference of 10°F in this assumption makes a difference of 4 to 6 percentage points in calculated cold start fraction.) The soak time to reach 130°F varies with engine size and ambient temperature, as follows:

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[263] Kearin, et al, "A Survey of Average Driving Patterns in Six Urban Areas of the United States", System Development Corporation Report TM-(L)-4119/007/00, January 1971. An analysis of the cold start implications of the SDC report appears in Vogt, "Hot Start/Cold Start Weighting Factors as Determined from the Study 'A Survey of Average Driving Patterns in Six Urban Areas of the United States'", Draft Report, Standards Development and Support Branch, ECTD, EPA, April 1976.

[264] Srubar, et al, "Soak Time Effects on Car Emissions and Fuel Economy", SAE paper 780083, February 1978.

Hours of Soak Time to Reach 130°F Engine Temperature
(Average of Oil and Water Temp; Initial Temp = 190°F)

Ambient Temp, °F	4-Cyl. Engine (2.3 litre)	8-Cyl. Engine (5.8 litre)
20	1.7	2.1
40	2.1	2.8
60	2.9	3.8
80	4.3	6.0

Average ambient temperatures, as a function of geographical region and season of the year[265], are shown in the following matrix, together with cold start soak times and cold start fractions computed using the foregoing data.

Cold Start Characteristics

		Average Temp. (F°)	STCS* (hrs)/Cold Start Fraction Small Cars	 Large Cars
Spring,	North	45.2	2.32/.420	3.05/.385
	South	62.0	2.98/.360	3.96/.315
Summer,	North	68.4	3.32/.376	4.46/.341
	South	77.6	4.07/.312	5.58/.274
Fall,	North	49.5	2.40/.415	3.18/.380
	South	64.5	3.10/.353	4.17/.307
Winter,	North	25.0	1.78/.453	2.22/.427
	South	47.6	2.36/.399	3.12/.352

VMT-Weighted Cold Start Fraction: $.385 \searrow .359 \swarrow .347$

*STCS = Soak time for cold start definition; defined here as time to reach 130°F engine temperature.

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[265] Newspaper Enterprise Association, The World Almanac and Book of Facts 1980, 1979.

Applying these weightings to the preceding relative MPG values, the cold/hot weighted relative MPG's are shown in the next matrix:

Cold/Hot Weighted Relative MPG
(EPA 55/45 = 1.000)

		Urban:		Rural:	
		Small Cars	Large Cars	Small Cars	Large Cars
Spring,	North	.935	.963	.957	.977
	South	.951	.978	.972	.992
Summer,	North	.971	.998	.989	1.007
	South	.976	1.003	.994	1.011
Fall,	North	.945	.973	.964	.983
	South	.956	.984	.973	.993
Winter,	North	.919	.946	.947	.967
	South	.943	.972	.970	.991
All		.950	.977	.971	.990

The overall 35.9% cold start fraction can be compared with the cold start fraction of the EPA combined City-Highway test[266]:

Cold Start Fraction, EPA 55/45 Test
(10,000 mile basis)

Urban trips, 5500 miles @ 7.47 miles/trip: 736 trips
Rural Trips, 4500 miles @ 10.24 miles/trip: 439 trips
Total: 1175 trips

Cold starts, 43% of urban trips: 316 starts
Hot starts, 57% of urban trips and all of rural trips: 859 starts

Cold start fraction, 316/1175: 26.9%

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[266] A determination of cold start fraction for emissions purposes would be conducted differently from this fuel economy-related analysis, and would address only the urban test, which is the only test used for emissions certification.

APPENDIX F

U.S. Average Road Fuel Economy, MPG
--Passenger Cars--

Source: DOT/FHwA VM-201A and VM-1 Tables

Pre-Emission Control:						Emission Control:	
1936	15.29	1947	14.95	1958	14.28	1968	13.79
1937	15.29	1948	14.96	1959	14.27	1969	13.63
1938	15.29	1949	14.97	1960	14.24	1970	13.57
1939	15.29	1950	14.95	1961	14.33	1971	13.57
1940	15.29	1951	14.99	1962	14.31	1972	13.49
1941	15.30	1952	14.67	1963	14.19	1973	13.10
1942	15.20	1953	14.70	1964	14.17	1974	13.43
1943	15.08	1954	14.58	1965	14.07	1975	13.53
1944	15.05	1955	14.53	1966	14.00	1976	13.72
1945	15.04	1956	14.36	1967	13.93	1977	13.94
1946	14.96	1957	14.39			1978	14.06

APPENDIX G

Fuel Economy Targets and Fuel Consumption Implications

A. Targets

"Target" fleet MPG values can be expressed in terms of percentage improvements, EPA figures, or on-road figures. The target for the voluntary improvement period (Section II) was expressed as a 40% improvement, by 1980, over 1974 levels. The mandatory improvement targets (standards) were specified in average 55/45 MPG terms, with an implied base level of 13.9 MPG for 1974. This 13.9 MPG figure was the best estimate of the 1974 models' average 55/45 MPG existing between October 1975 and January 1978, the interval during which the standards were set[267]. No targets have (thus far) been expressed in terms of road MPG. The following table lists the specified EPA 55/45 targets, all using the 13.9 MPG value for 1974 that they were based on, and the road targets *implied* by the specified targets, using the current best estimate for the 1974 models' *road* fuel economy, 13.23 MPG (See Section V.A.).

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[267] EPA estimates of 13.9 MPG for 1974 were published in Austin, *et al*, "Passenger Car Fuel Economy Trends Through 1976", SAE Paper 750957, October 1975, and again in Murrell, *et al*, "Light-Duty Automotive Fuel Economy Trends Through 1977, SAE Paper 760795, October 1976. (Updated retrospective estimates of the 1974 models' fleet average fuel economy have since been published, beginning with Murrell, "Light Duty Automotive Fuel Economy...Trends through 1978, SAE Paper 780036, February 1978.)

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Target Fleet Fuel Economy Values,
EPA and Road

Model Year	Voluntary Program		Mandatory Program	
	Specified Target	Implied EPA 55/45 Target	Specified Target, EPA 55/45	Implied Road Target
1974	---	13.9 Base		13.23 Base
1975	1.067x1974	14.83		14.12
1976	1.133x1974	15.75		14.99
1977	1.200x1974	16.68		15.88
1978	1.267x1974	17.61	18.0	17.13
1979	1.333x1974	18.53	19.0	18.08
1980	1.400x1974	19.46	20.0	19.04
1981	---	---	22.0	20.94
1982	---	---	24.0	22.84
1983	---	---	26.0	24.75
1984	---	---	27.0	25.70
1985	1.733x1974	24.09	27.5, 26.0 minimum	26.17, 24.75 minimum

XX = specified

YY = implied

B. Fuel Consumption

A simplified model[268] was used to investigate the sensitivity of total U.S. passenger car fleet fuel consumption to the road target values above, and to the maximum and minimum bounds of in-use fuel economy from Section III. The size of the fleet was held constant at 100 million vehicles, so that all observed fuel consumption effects would be due to fuel economy factors only, and not to growth in the vehicle population, VMT/car/year, or total VMT. The model's assumptions for annual miles traveled, and vehicle scrappage rates, as a function of vehicle age, are given in the reference. The results of this sensitivity study are shown in the following tables.

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[268] Ward and Thompson, "Prediction of U.S. Annual Fuel Consumption by Passenger Automobiles", Report SDSB 79-12, Standards Development and Support Branch, ECTD, EPA, 1979.

INPUT DATA: Average Road Fuel Economy, MPG

--Individual Model Years --

Model Year	Road MPG
1974	13.23
1975	13.83
1976	14.11
1977	14.72
1978	15.81
1979	16.87
1980	15.7 - 18.7
1981	16.2 - 20.1
1982	16.7 - 21.3
1983	17.1 - 22.6
1984	17.3 - 23.1
1985 - 2000	17.5 - 23.5

OUTPUT DATA:

U.S. PASSENGER CAR FLEET FUEL CONSUMPTION
(FLEET SIZE = 100 MILLION)

CALENDAR YEAR	ANNUAL FUEL CONSUMPTION (BILLION GAL/YR) TARGET	HIGH	LOW	(MILLION BBL/DAY) TARGET	HIGH	LOW	CUMULATIVE FUEL CONSUMPTION (BILLION GALLONS) TARGET	HIGH	LOW	(BILLION BARRELS) TARGET	HIGH	LOW
1974	70.4	70.4	70.4	4.59	4.59	4.59	0	0	0	0	0	0
1975	70.0	70.1	70.1	4.57	4.57	4.57	70	70	70	1.7	1.7	1.7
1976	69.2	69.6	69.6	4.51	4.54	4.54	139	140	140	3.3	3.3	3.3
1977	68.0	68.9	68.9	4.43	4.49	4.49	207	209	209	4.9	5.0	5.0
1978	66.3	67.7	67.7	4.32	4.42	4.42	273	276	276	6.5	6.6	6.6
1979	64.0	66.0	66.0	4.18	4.31	4.31	337	342	342	8.0	8.2	8.2
1980	61.6	63.8	64.4	4.02	4.16	4.20	399	406	407	9.5	9.7	9.7
1981	58.9	61.1	63.2	3.84	3.99	4.12	458	467	470	10.9	11.1	11.2
1982	55.8	58.2	61.6	3.64	3.80	4.02	514	526	531	12.2	12.5	12.7
1983	52.7	55.2	60.1	3.44	3.60	3.92	566	581	592	13.5	13.8	14.1
1984	49.5	52.2	58.9	3.23	3.41	3.84	616	633	650	14.7	15.1	15.5
1985	46.6	49.5	57.7	3.04	3.23	3.76	663	683	708	15.8	16.3	16.9
1986	44.0	47.1	56.5	2.87	3.07	3.69	707	730	765	16.8	17.4	18.2
1987	41.8	45.1	55.6	2.73	2.94	3.63	748	775	820	17.8	18.4	19.5
1988	40.1	43.5	54.9	2.61	2.84	3.58	788	818	875	18.8	19.5	20.8
1989	38.7	42.3	54.4	2.52	2.76	3.55	827	861	930	19.7	20.5	22.1
1990	37.7	41.3	53.9	2.46	2.70	3.52	865	902	983	20.6	21.5	23.4
1991	36.9	40.7	53.6	2.41	2.65	3.50	902	943	1037	21.5	22.4	24.7
1992	36.4	40.2	53.4	2.38	2.62	3.49	938	983	1091	22.3	23.4	26.0
1993	36.1	39.9	53.3	2.35	2.60	3.47	974	1023	1144	23.2	24.3	27.2
1994	35.8	39.7	53.2	2.34	2.59	3.47	1010	1062	1197	24.0	25.3	28.5
1995	35.7	39.6	53.1	2.33	2.58	3.46	1046	1102	1250	24.9	26.2	29.8
1996	35.6	39.5	53.1	2.32	2.58	3.46	1081	1142	1303	25.7	27.2	31.0
1997	35.6	39.5	53.0	2.32	2.58	3.46	1117	1181	1356	26.6	28.1	32.3
1998	35.6	39.5	53.0	2.32	2.58	3.46	1153	1221	1409	27.4	29.1	33.6
1999	35.6	39.5	53.0	2.32	2.58	3.46	1188	1260	1462	28.3	30.0	34.8
2000	35.6	39.5	53.0	2.32	2.58	3.46	1224	1300	1515	29.1	30.9	36.1

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

SEP 29 1980

THE ADMINISTRATOR

Honorable Walter F. Mondale
President of the Senate
Washington, D.C. 20510

Dear Mr. President:

In accordance with section 404 of the National Energy Conservation Policy Act, I am transmitting to Congress the enclosed document entitled "Passenger Car Fuel Economy: EPA and Road." This is a detailed report on the degree to which fuel economy estimates, required to be used in new car fuel economy labeling and in the annual fuel economy mileage guide, provide a realistic estimate of average fuel economy likely to be achieved by the driving public.

If there are any questions, or if additional information is needed, please call me, or your staff may want to call Gregory Dana at 755-0596.

Sincerely yours,

Douglas M. Costle

Enclosure

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

SEP 29 1980

THE ADMINISTRATOR

Honorable Thomas P. O'Neill, Jr.
Speaker of the House of Representatives
Washington, D.C. 20515

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Douglas M. Costle

Enclosure

ENVIRONMENTAL PROTECTION AGENCY
Motor Vehicle Emission Laboratory
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